# LIVESTOCK AND DERIVED FEED DEMAND IN THE WORLD GOL MODEL

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## ABSTRACT

Projected alternatives imply that the world livestock sector acts as a large secondary world grain reserve. This conclusion emerges from analysis of the projection performance, economic structure, and documentation of the livestock sector in the World GOL Model, a computer model of the world grain, oilseed, livestock (GOL) economy. This study provides documentation for demand and supply elasticities and feed input-output coefficients in the equations constituting a third of the GOL model. Developed regions prove to have adequate data for developing reasonable estimates of parameters for those regions. They account for the bulk of world production and consumption of livestock products and are the high-priority regions for representative modeling of the world. World cross-section meat and grain demand functions and behavioral livestock feeding functions are applied to obtain estimates of structural parameters for regions with poor data.

Key words: World projections, agricultural commodities, livestock products, livestock feed, grain, oilseeds, mathematical model.

## ACKNOWLEDGMENTS

The World GOL Model was developed by the Economics, Statistics, and Cooperatives Service (ESCS), U.S. Department of Agriculture. It is a mathematical representation of the combined grain-oilseed-livestock (GOL) commodity sectors of the world economy. Its purpose is to aid in long-range commodity projections of the world. It is the result of joint effort among numerous participants--mainly,

| | |
|---|---|
| Anthony S. Rojko | --Originator and leader of the GOL project |
| Donald W. Regier | --Livestock and derived feed |
| Patrick M. O'Brien | --Grains |
| Arthur L. Coffing | --Oilseeds |
| Robert D. Barry | --Rice |
| Myles J. Mielke | --Dairy products |
| Linda M. Bailey | --Statistical support |

--involving continuing consultation with other ESCS commodity and projection specialists and international country analysts. The World GOL Model is essentially Rojko's in scope, design, and much of the detail. Persons contributing to the development of the computer program are Francis S. Urban, Roger P. Strickland, Hilarius Fuchs, Fenton Sands, and Martin Schwartz. The author is also indebted to Howard H. Conley (dairy and computer) and Phillip Paarlberg (oilseeds) who are new team members, Lyle Schertz, Joseph W. Willett, Carmen O. Nohre, and to Deborah Merrigan, and Jan Feldstein Lipson.

Developed regions prove to have sufficiently reliable data for making estimates of the parameters of the World GOL Model. These regions are those that, on a world scale, account for the bulk of both production and consumption of livestock products and are the major components of the commercial meat economy of the world.

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# FOREWARD

The Economics, Statistics, and Cooperatives Service (ESCS) is continuously working on projections of changes in world export markets, population, income, and resource and environmental constraints and on projections of their impact on U.S. agriculture. The affected U.S. variables include production, consumption, trade, prices, farm costs, and farm income.

Major components of the projections program are world, regional, and country projections of production, demand, trade, and prices of major commodities important in agricultural trade. These projections are useful in evaluating the broad issues of future world food prospects.

The projections are made within the framework of a mathematical world grain-oilseed-livestock (GOL) model. The model is designed to capture the main economic relationships of the three groups of commodities and to test the impact of different economic and policy assumptions on projected quantities and values.

Projections of U.S. agricultural exports generated by the GOL model are not official ESCS projections of U.S. trade in agricultural commodities. Rather, they are presented to aid users in evaluating the impact of different assumptions on world trade.

Results of using the GOL model have been reported separately in volumes entitled Alternative Futures for World Food in 1985. Under this comprehensive heading, Volume 1, World GOL Model Analytical Report and Volume 2, World GOL Model Supply-Distribution and Related Tables present projections, describe scenarios, and interpret results. Volume 3, World GOL Model Structure and Equations presents the full economic model. The present study documents the mathematical terms in the livestock part of the model and the demand for livestock feed.

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Results of the alternatives projected by the World GOL Model of the world grain, oilseed, livestock (GOL) economy imply that the livestock sector acts as a large secondary grain reserve. Situated mainly in the developed countries, the sector appears to act as a governor, or stabilizer, for regulating world rates of production, consumption, and prices of grain. Under stress of low world grain production, GOL projections for 1985 show reduced grain feeding to livestock in the developed countries, mainly the United States and Europe, while world grain consumption for food declines by far less. With high grain output, the GOL model projects lowered feed prices (associated with increased grain feeding and expanded output from the developed countries of meat and other feed intensive livestock products), higher meat consumption, and slightly increased grain consumption for food. Alternatives thus far projected for 1985 show meat production and consumption and grain for food varying about 10 percent, whereas feed grain demand varies about 20 percent.

Just as the countries and regions of the world fall into a sequence of affluence when classified by per capita national income, they conform to a similar sequence when classified by per capita consumption of meat, grain, and food. Significantly for the GOL model, the intensity of livestock feeding (per unit of product obtained) also conforms to the sequence. Thus, meat and grain consumption and livestock feeding prove to be functions of per capita income on a world scale.

The properties of this world sequence are quantified and applied to the problem of obtaining estimates of elasticities of demand and supply and of feed conversion rates for regions where data are unreliable.

# LIVESTOCK AND DERIVED FEED DEMAND IN THE WORLD GOL MODEL

*Donald W. Regier**

## INTRODUCTION

Developments over the past few years have sharply focused world attention on the performance of the agricultural economy. During this period--

- World agricultural prices have been high and unstable.
- Formerly extensive world grain stocks held by major exporting countries were suddenly reduced to low levels.

Now it seems likely there will be a return to high levels of grain stocks.

The endeavor to analyze such developments as these opens up a series of critical questions requiring quantified answers. Some of these questions are--

- What tradeoff is there between uses of grain as human food and as livestock feed?
- What are the implications of high livestock prices and growing livestock production for world availability of grain for use as food?
- What is the effect of high livestock prices on world allocation of grain and oilmeal?
- What is the likely effect of recourse to protectionism on world agricultural trade and on allocation of world food supplies?
- What is the effect of high grain prices on meat production and trade?
- What is the role of the world livestock sector as a secondary grain reserve?

To shed light on such concerns as these, the Economics, Statistics, and Cooperatives Service (ESCS), U.S. Department of Agriculture (USDA), has developed a mathematical model of the combined grain, oilseed, and livestock (GOL) commodity sectors of the world. The World GOL Model (157, 158, 159, and 160) analyzes the economic interrelationships between the world grain economy (worldwide in scope), the world commercial meat economy (concentrated in a reduced number of regions), and the oilseed economy (in still fewer regions).1/ The issues raised above, in general, require the full GOL model for their evaluation, but the livestock sector by itself can shed light on some of them.

Results of alternative projections made with the World GOL Model imply that the world livestock economy plays a critical role in analyzing such developments and questions as those stated above and acts as a large secondary grain reserve. Sit-

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* Regier is an agricultural economist with the Foreign Demand and Competition Division of the Economics, Statistics, and Cooperatives Service, U.S. Department of Agriculture.

1/ Underscored numbers in parentheses refer to references listed at the end of this report.

uated mainly in the developed countries, the sector appears to serve as a governor, or stabilizer, for regulating world rates of production, consumption, and prices of grain. Under stress of low world grain production, GOL projections for 1985 show reduced grain feeding to livestock in the developed countries, mainly the United States and Europe, while world grain consumption for food declines far less. With high grain output, the GOL model projects lowered feed prices associated with increased grain feeding and expanded developed country output of meat and other feed intensive livestock products, higher meat consumption, and slightly increased grain consumption for food. Alternatives thus far projected for 1985 show meat production and consumption and grain for food varying about 10 percent, whereas feed grain demand varies about 20 percent.

The focus in this report is on the economics and mathematics of the livestock part of the World GOL Model, its internal working, and its articulation with the grain and oilseed parts (147). Appendix A contains a brief statement of the broad aspects of the model and its background.

This study is an exposition of the structure of the livestock sector of the World GOL Model for long-range projection to 1985 and beyond. It documents and presents the rationale for the demand and supply elasticities that were used and the feed input-output coefficients that tie crop and livestock sectors together. It is designed to be used along with other studies based on the GOL model. It is intended for use by researchers, analysts, and economists who are concerned with longrun projections of the commodities of the feed-livestock complex, desire a clearer understanding of production, trade, and price formation in this context, or require a precise understanding of the structural assumptions that are built into the model's livestock sector and affect its projections.

## STRUCTURE OF THE WORLD GOL MODEL

The livestock sector is deeply imbedded in the world feed-livestock economy. Comprehension of the role of the livestock sector, therefore, requires an overview of the structure of the full world model.

### The Model

The World GOL Model (see 147, 157, 158, 159, and 160) is a mathematical system of 930 simultaneous equations which are solved by computer to project 930 interacting variables. It projects by region individual crop areas of the world and the quantity of supply and distribution, net trade, and prices for each commodity of the feed-livestock complex. There are 12 commodities in this group: wheat, coarse grain (including corn), rice, oilmeal, soybeans, beef and veal, pork, poultry, mutton, milk, butter, and cheese. Finished beef is identified in the United States, aggregate grain is used in the feed equations, and total meat is calculated. The world has 28 regions, including a residual. Regions are not symmetrically modeled. All regions have crop equations, but not necessarily for all crops. Only half of the regions have livestock equations at this stage of modeling. The central plan regions have only reduced-form net trade equations. The U.S. sector included in GOL is intended to be representative only. Full U.S. models are used along with GOL in the ongoing USDA-ESCS projection program (105, 143, 144, and 162).

The equations included in the GOL model typically contain parts that belong among the 930 interacting variables and parts that do not. Functions of the variables that are endogenous to GOL (the 930 variables) are designated F, while functions of variables that are exogenous to GOL are indicated as G. All F-functions are required to be linear, because of the methods used for solving the 930-equation simultaneous system. The G-functions are not required to be linear. The form of the GOL equation structure is closely related to the form in which the results of agricultural economics research typically are presented (see appendix A).

Within a region, the World GOL Model consists of eight major blocks of equations:

1. Demand block: livestock products
2. Supply block: livestock products
3. Demand block: feed crops
4. Demand block: food crops
5. Supply block: crops
6. Price linkages
7. Regional equilibrium
8. World equilibrium.

The broad relationships among these blocks are shown schematically in figure 1. The block numbers in the listing above agree with the position numbers in figure 1 and also with the equation forms shown in figure 2. Thus, any discussion of equation blocks by number may be referred immediately to both figures 1 and 2.

Blocks defining demand for human food are numbered 1 and 4. Equations in these blocks show food commodities as F-functions of direct prices and prices of competing and complementary goods. They are G-functions of per capita income, population, and a time trend or other factors representing, for example, adoption of Western ways.

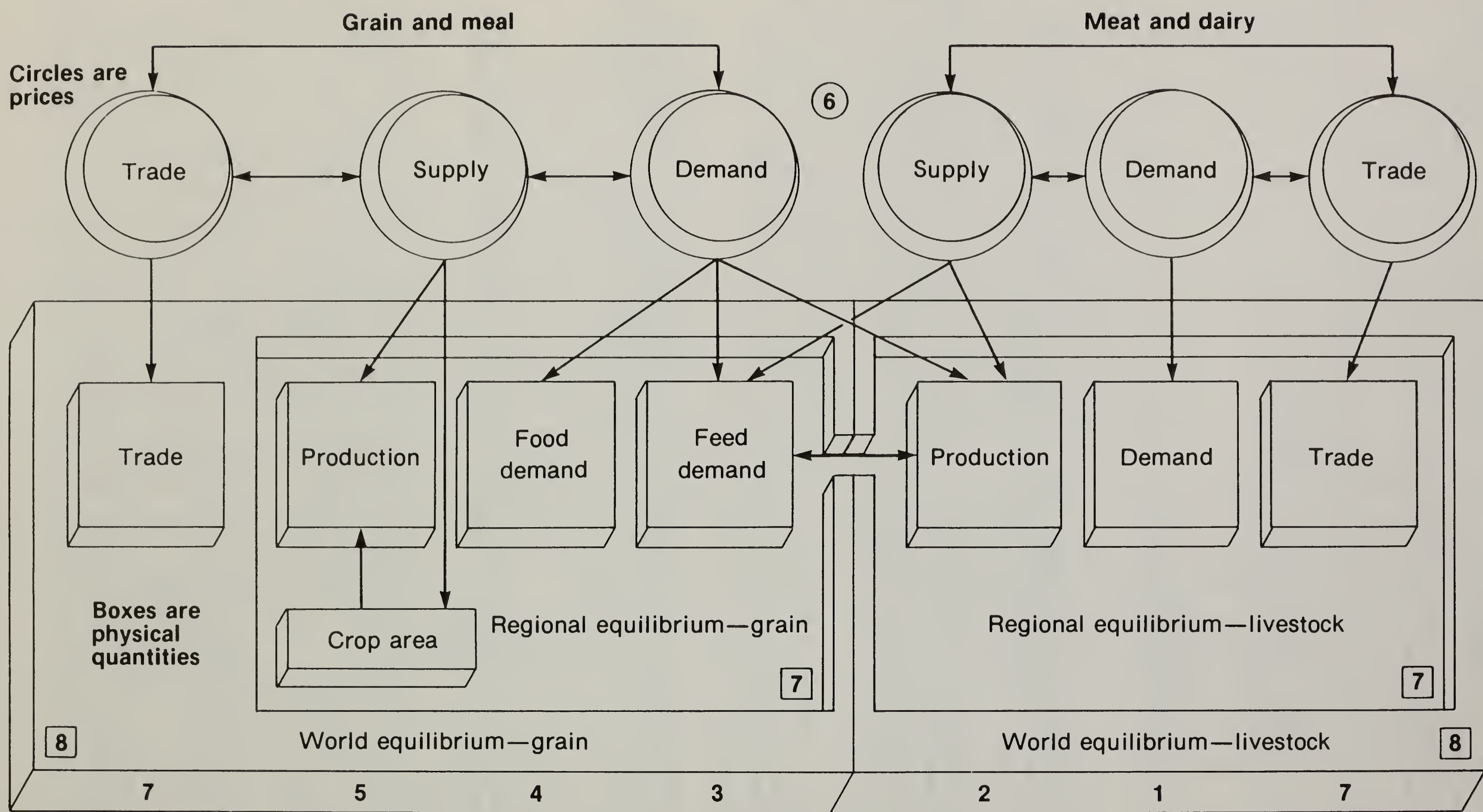
Block 2 defines livestock production. Meat production illustrated by beef, is shown as an F-function of individual meat prices to allow for competition among meats and of prices of corn and oilmeal to allow for real costs of production. It is a G-function of productivity.

Feed demand, defined in block 3, serves as the link between the livestock and crop sectors of the GOL complex. Separate crop prices allow for competition between feed crops, while livestock product prices guide the direction of product expansion and serve to adjust feed demand. The basic linkage, however, is a set of physical input-output rates expressing the tons of grain or meal used to produce a ton of a given livestock product. This tie is shown in figure 1 by a direct connection between blocks 2 and 3. The ties and linkages are all F-functions. G-functions, when present, contain productivity factors. Variables such as per capita income, population, and taste change are associated with those parts of the livestock economy not fully modeled.

Livestock and feed equations (blocks 1, 2, and 3) appear in only half of the 28 regions in the GOL model, but they account for a third of the 930-equation system. The feed equations (block 3) contain fully half of the livestock variables. Details of the equations in blocks 1, 2, and 3 constitute the remainder of this study. The other equation blocks are discussed, because the World GOL Model is an organic unit.

Crop production, including both grains and oilseeds, is determined within block 5 by two basic sub-blocks linked by a key equation for each region. Total crop area is determined for each GOL region by F-functions of prices of the most important crops, and G-functions of factors such as reclamation, urbanization, and policies affecting the area under cultivation. The area of individual crops is determined by F-functions expressing effects of historical shares of land and prices of competing crops. Production is an F-function of individual crop area and direct crop prices. Production has the form of a yield equation with varying area--a compromise

## World GOL Model: Supply and demand sectors in a typical region




**Numbers are GOL equation blocks**

1 Demand block: livestock products
2 Supply block: livestock products
3 Demand block: feed crops
4 Demand block: food crops
5 Supply block: crops (area and production)
6 Price linkages: levels, margins, distance
7 Regional equilibrium: defining balance in a region among blocks 1 through 6
8 World equilibrium: equating world production with consumption; balancing regional trade

Figure 1

World GOL Model: Typical equation forms associated with the major equation blocks

| | |
|---|---|
| **Block 1** | |
| • Beef demand | = F (prices of beef, pork, poultry)<br>+ G (per capita income, population, changing tastes, policy factors) |
| **Block 2** | |
| • Beef production | = F (prices of beef, milk, pork, corn, oilmeal)<br>+ G (productivity growth, technology) |
| **Block 3** | |
| • Feed grain demand | = F (physical production of beef, pork, poultry, milk; prices of beef, pork, corn, oilmeal)<br>+ G (per capita income, population, productivity growth, changing tastes, policy factors) |
| • Feed wheat demand | = F (feed grain demand; prices of wheat, corn) |
| • Feed corn demand | = Feed grain demand<br>- Feed wheat demand |
| **Block 4** | |
| • Food wheat demand | = F (prices of wheat, corn, rice)<br>+ G (per capita income, population, changing tastes, policy factors) |
| **Block 5** | |
| • Total crop area | = F (prices of wheat, corn, rice, oilseeds)<br>+ G (reclamation, irrigation, urbanization, technology growth) |
| • Wheat area | = F (total crop area; prices of wheat, corn, oilseeds) |
| • Wheat production | = F (wheat area; price of wheat)<br>+ G (exogenous physical input bundle, weather) |
| **Block 6** | |
| • Supply price of beef | = F (demand price of beef)<br>+ G (productivity growth, policy factors) |
| • Demand price of wheat in region 1 | = F (demand price of wheat in region 2)<br>+ G (productivity growth, policy factors) |
| **Block 7** | |
| • Supply of wheat in region 1 | = Food demand for wheat in region 1<br>+ Feed demand for wheat in region 1<br>- Trade in wheat by region 1 |
| **Block 8** | |
| • World supply of wheat in all regions | = World demand for wheat in all regions |
| • World exports of wheat to all regions | = World imports of wheat from all regions |

Figure 2

solution to conserve linearity where multiplication of area by yield to obtain production is ruled out by the computer program used.

Price linkages constituting block 6, indicated by the circled values at position 6 in figure 1, define the margins and levels relating demand, supply, and trade prices and the connections between these and wholesale or international trade prices. Most terms in the price linkages are F-functions, but some growth and productivity factors are G-functions.

Regional equilibrium conditions comprising block 7 state the physical conditions of international trade between regions and the international propagation of price impulses. They are suggested as two rectangles marked 7, which include blocks numbered 1 through 5 and which may or may not contain the trade blocks shown as positions 7. Figure 1 is drawn to illustrate a region exporting grain and importing meat or other livestock products. The region in figure 1 might be the United States. Net exports are treated as positive trade, while net imports are negative.

World equilibrium conditions are stated in block 8 and are illustrated in figure 1 as two comprehensive panels which embrace blocks 1 through 5 and block 7. They provide for summing all regions to obtain world totals, with production equal to consumption of each commodity at a harmonious pattern of regional prices and with world exports equal to world imports.

At the heart of the GOL model is the modeling of the feed demand block; that is the interfacing between blocks 2 and 3. The specification outlined above applies to developed countries and to regions belonging to the commercial meat economy. The design structure for such a region is as shown in figure 3. A four-level regional equilibrium is depicted involving grain, oilmeal, meat, and dairy products, with exogenous forces acting from above and below in a sphere of regional price effects. Trade and price forces are carried to other regions.

For regions with only a modest livestock economy and little foreign trade in animal products, another approach is used. The livestock demand and supply blocks are collapsed into block 3 (the method is shown in appendix D). Livestock demand and supply vanish as separate specifications, as is shown in figure 4, leaving the feed demand block 3 in altered form. The feed demand functions are now reduced-form expressions in which the demand for feed is a function of the determinants of both demand and supply of livestock products and of the livestock feeding rates. In short, the demand for feed contains the factors determining demand for livestock products. These factors, however, are no longer explicitly expressed.

While grappling with the interrelatedness of the world feed-livestock economy and broad regional similarities, the World GOL Model attempts to recognize the lack of entire symmetry in the geographical patterns of the livestock complex. Table 1 illustrates some of the most important regional differences. The indicated equation structure highlights those regions that (1) produce or consume mainly grain, (2) consume significant quantities of livestock products, (3) produce commercially important quantities of livestock products, (4) employ sufficient quantities of feedstuffs to justify incorporating feed demand equations into the model, and/or (5) are represented in the world model structure, at this stage, only by net trade equations. The equation specification of individual regions can be grasped at a glance. Table 1, thus, serves as a schematic index to the equation structure to be found in each region.

Table 1--World GOL Model: Variables used 1/

| Country or region | Wheat | Rice | Coarse grain | Oilseed meal | Milk | Cheese | Eggs | Beef cuts | Beef products | Pork | Poultry | Mutton and lamb |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Developed countries: | | | | | | | | | | | | |
| United States | DF PA | D PA | DF PA | F PA | D S | D S | P | D P | D P | D P | D P | D |
| Canada | DF PA | D | DF PA | F PA | D S | D S | P | -- | D P | D P | D P | -- |
| EC-6 | DF PA | D PA | DF PA | F PA | D S | D S | P | -- | D P | D P | D P | D P |
| EC-3 | DF PA | D PA | DF PA | F PA | D S | D S | P | -- | D P | D P | D P | D P |
| Other Western Europe | DF PA | D PA | DF PA | F PA | D S | D S | -- | | D P | D P | D P | D P |
| Japan | D PA | DF PA | DF PA | DF PA | D S | D S | P | -- | D P | D P | D P | D P |
| Australia and New Zealand | DF PA | D PA | DF PA | F PA | D S | D S | P | -- | D P | D P | D P | D |
| South Africa | D PA | D | DF PA | F S | -- | D S | -- | -- | D P | D P | P | D P |
| Centrally planned countries: | | | | | | | | | | | | |
| Eastern Europe | T | T | T | T | -- | -- | -- | -- | T | T | -- | -- |
| Soviet Union | T | T | T | T | -- | -- | -- | -- | T | -- | -- | -- |
| China | T | T | T | T | -- | -- | -- | -- | -- | T | -- | -- |
| Developing countries: | | | | | | | | | | | | |
| Middle America | DF PA | D PA | DF PA | F PA | -- | -- | -- | -- | D P | D P | -- | -- |
| Argentian | D PA | D PA | DF PA | F PA | -- | -- | -- | -- | D P | D P | -- | D P |
| Brazil | D PA | D PA | DF PA | F PA | -- | -- | -- | -- | D P | D P | -- | -- |
| Venezuela | D PA | D PA | DF PA | F PA | -- | -- | -- | -- | -- | -- | -- | -- |
| Other South America | D PA | D PA | DF PA | F PA | -- | -- | -- | -- | -- | -- | -- | -- |
| High income North Africa and Middle East | D PA | D PA | DF PA | F | -- | -- | -- | -- | -- | -- | -- | -- |
| Low income North Africa and Middle East | D PA | D PA | DF PA | S | -- | -- | -- | -- | -- | -- | -- | -- |
| East Africa | D PA | D PA | DF PA | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| Central Africa | D S | D S | D S | T | -- | -- | -- | -- | -- | -- | -- | -- |
| India | D PA | D PA | DF PA | F PA | -- | -- | -- | -- | -- | -- | -- | -- |
| Other South Asia | D PA | D PA | D PA | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| Thailand | D | D PA | DF PA | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| Other Southeast Asia | D | D PA | DF S | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| Indonesia | D | D PA | D PA | D PA | -- | -- | -- | -- | -- | -- | -- | -- |
| High income East Asia | D PA | D PA | DF PA | F PA | -- | -- | -- | -- | -- | -- | -- | -- |
| Low income East Asia | D | D PA | DF PA | S | -- | -- | -- | -- | -- | -- | -- | -- |
| Rest of world | -- | -- | -- | -- | -- | T | -- | -- | T | T | -- | T |

-- = Not applicable.
1/ D = Demand, total or nonfeed, F = derived demand for feed, P = Production, A = Area, S = supply, and T = foreign trade, net.

Sources: (157 and 158).

## World GOL Model: Region with a full livestock sector

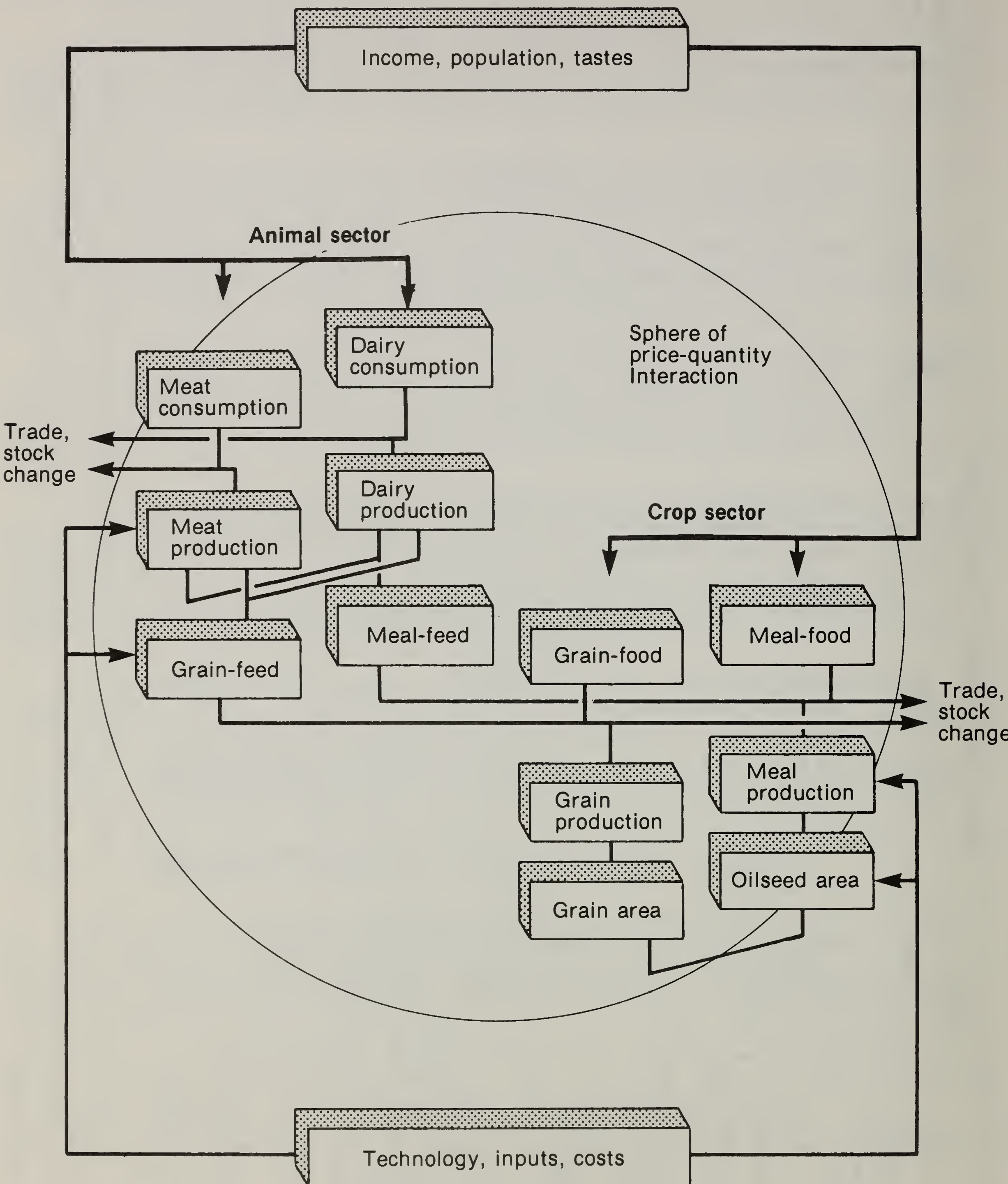



Figure 3

## World GOL Model: Region with a collapsed livestock sector

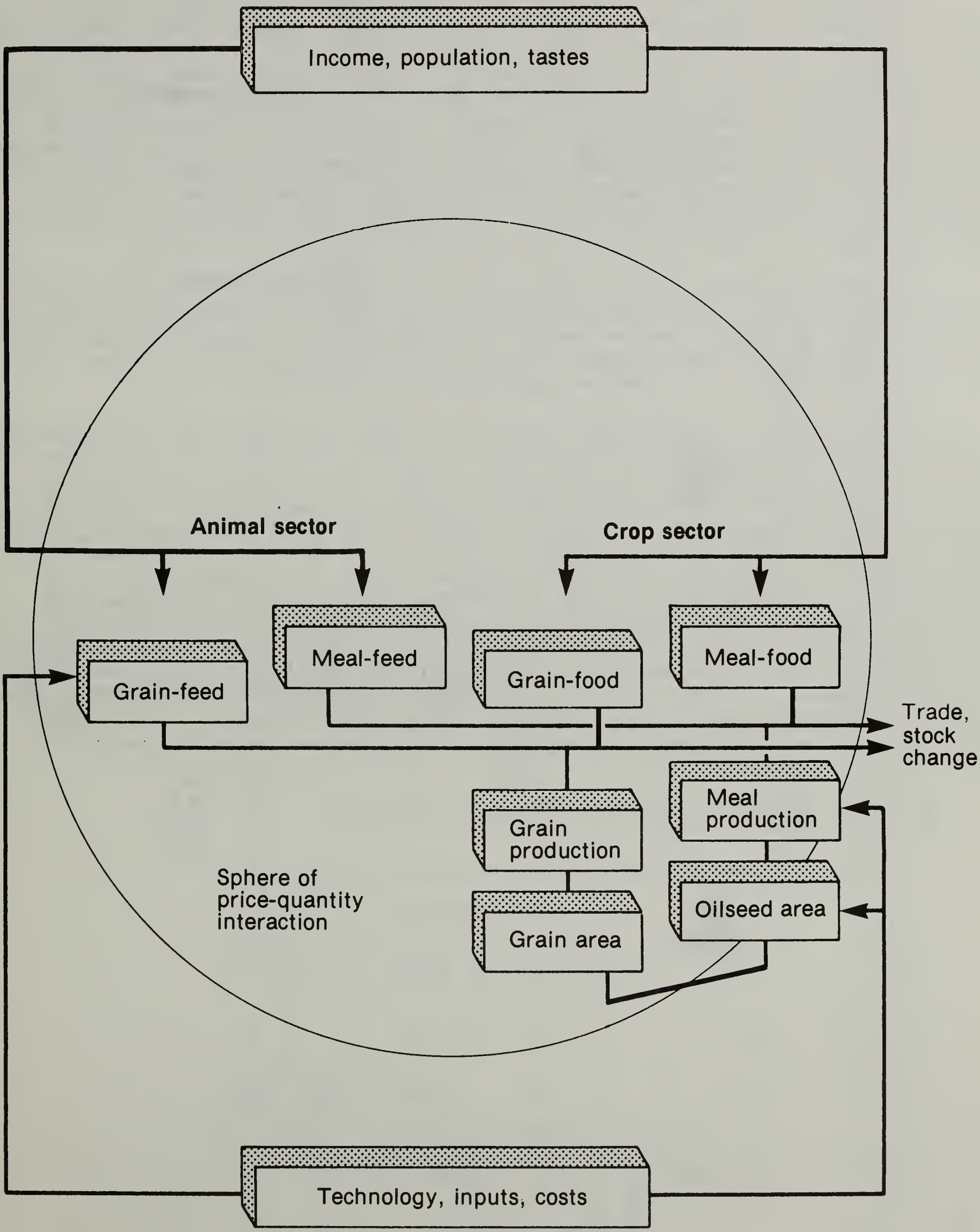



Figure 4

## The World

In large measure, table 1 confirms that the GOL model follows priorities of scale and relative importance in the world meat economy. Figure 5 describes the world commercial meat economy in the 1970 base of the World GOL Model. Arrows indicate the direction of flows of trade in meat, mainly beef. The white areas in the circles are proportional to local meat consumption, among world regions, shaded areas indicate imports, and black areas indicate net exports. North America and Western Europe dominate commercial meat consumption, and are the targets for the important flows of long distance meat trade. A number of regions are shown without trade arrows, because the flows lack the systematic nature of the main trade; however, the lack of arrows indicates low priorities of scale. The central plan countries are sporadic meat importers, but show signs of becoming systematic importers.

The World GOL Model presents another departure from symmetry. In each region representing a central plan authority, and for each commodity important in international trade, a single equation has been synthesized to express net foreign trade in relationship to the usual demand and supply determinants and other factors. The equations have the form of classical excess-demand functions.

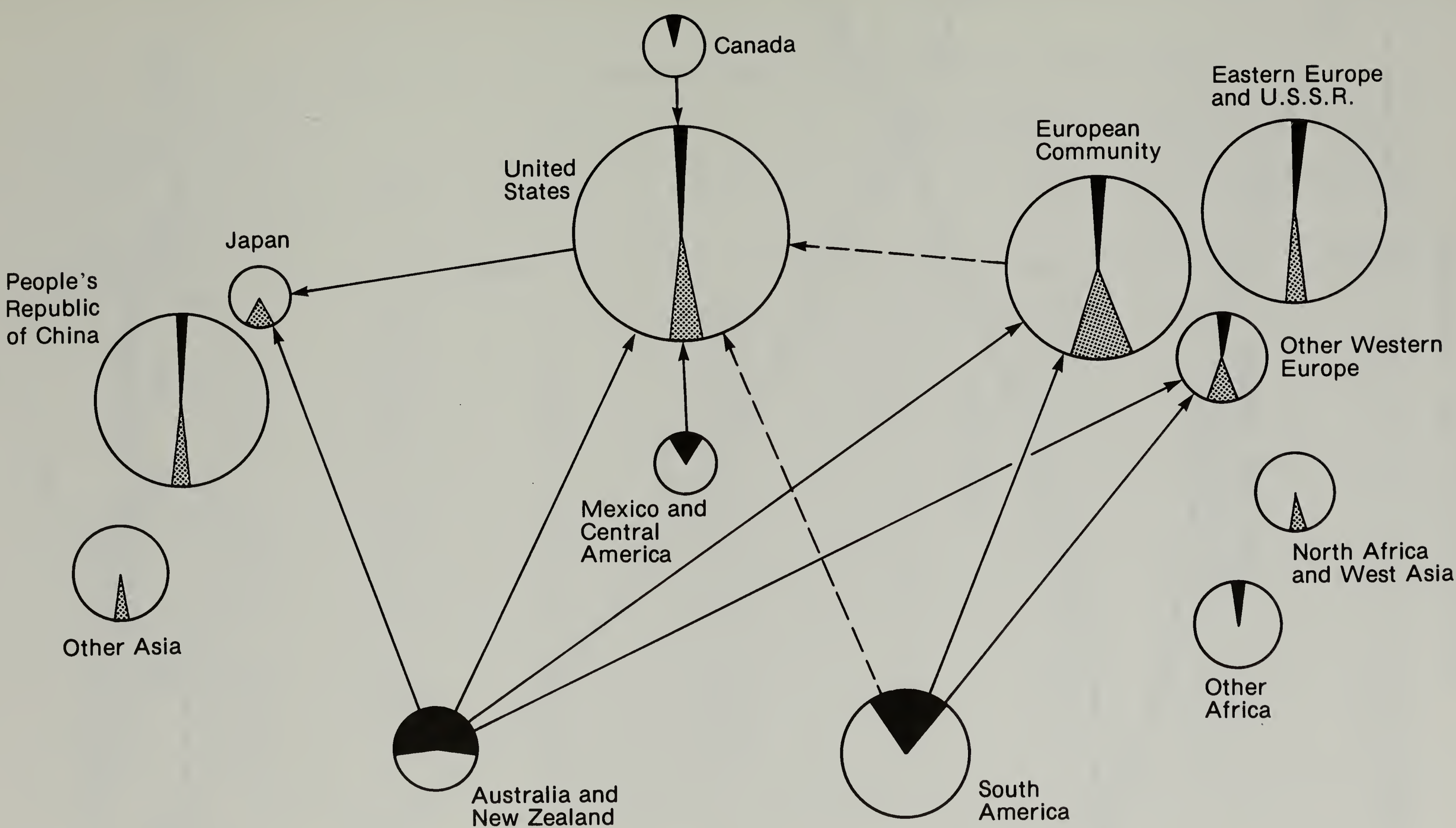
Underlying the entire World GOL Model in its major commodity sectors, there runs a global unity which shows up with peculiar clarity in the livestock sector. Countries form a progression both when classified on a scale of per capita income and when classified by quantity consumed per capita of meat or the proportion of grain allocated to livestock production, as shown in figure 6 and table 2 (see appendix B and 148). Grain allocated to human food and to feed at the expense of food also tends to conform to the sequence. Thus, in regions with poor data, a basis exists for judgment as to the intensity of grain and oilmeal feeding in the production of livestock products. This progression is referred to here as the Main Sequence. In much the way that the work of Le Play (1048) and Engel (1017) made possible prediction of dietary patterns in European worker families of the mid-1800's through knowledge of their incomes, observed variation in feeding rates and allocation of feed to livestock is predictable over much of the world from the Main Sequence. World demand functions have been calculated for meat and grain, and demand elasticities derived (see table 2 and appendix B).

World demand elasticities are calculated as follows:

| Commodity | Price elasticity | | Income elasticity |
|---|---|---|---|
| | Meat | Grain | |
| Meat | -.60 | .60 | .60 |
| Grain | .43 | -.43 | -.14 |

Sources: Main Sequence equations, appendix B, and (148).

## World meat economy

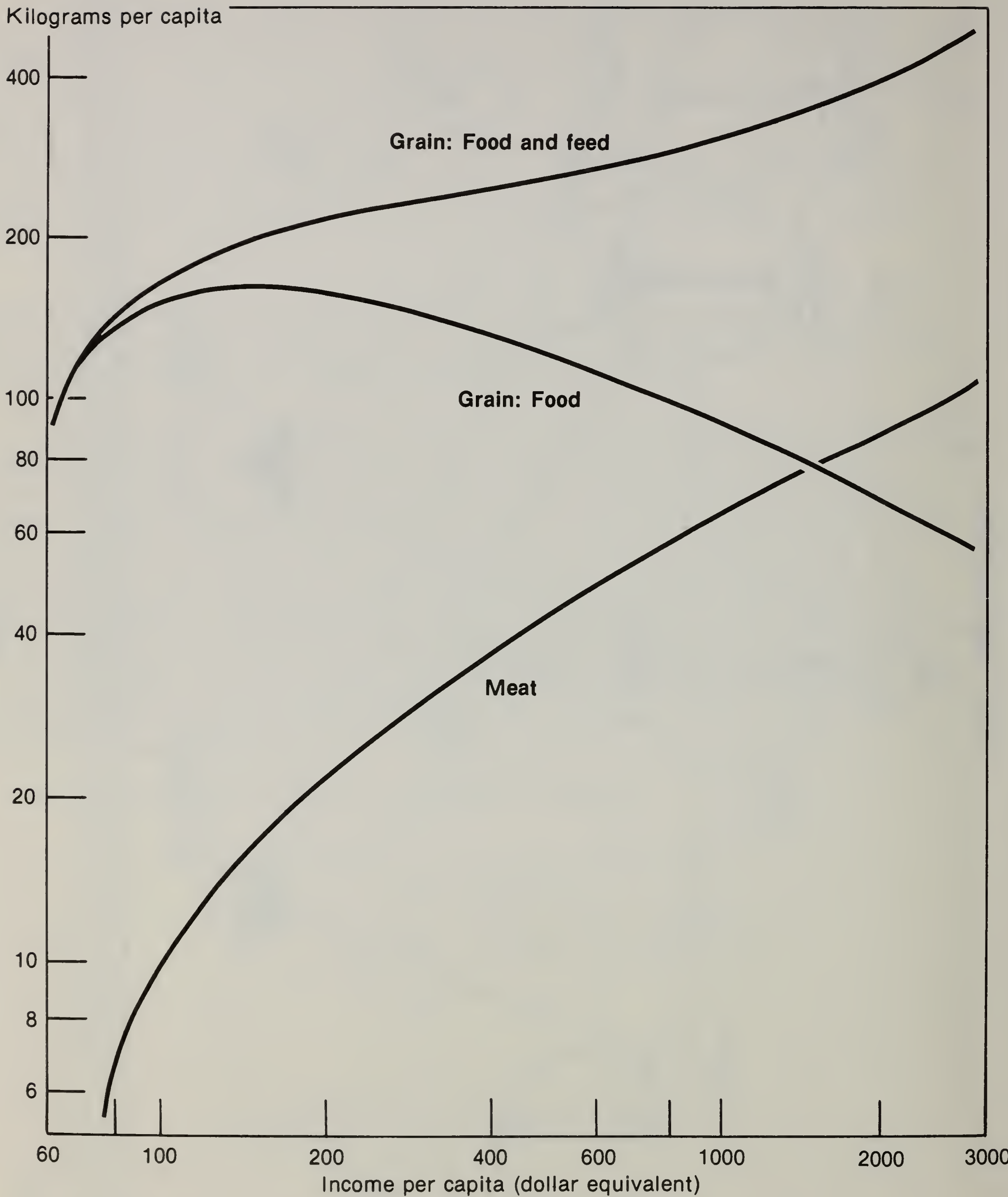



*Meat includes all bovine meat (including beef, veal, and buffalo), and all pig meat, poultry meat, lamb, mutton, and goat meat, and other meat (including horse meat and game). White areas of circles are proportional to meat consumption among world regions. Shaded areas indicate imports. Black areas indicate exports. Arrows with solid lines indicate unrestricted trade as to aphthous fever (foot and mouth disease) and represent live animals or fresh meat (chilled or frozen). Arrows with broken lines indicate trade restricted to cooked meat only (canned or frozen).*

*Source: (146).*

**Figure 5**

## World grain and meat consumption




*Sources: Main sequence equations, Appendix B, and (148).*

Figure 6

Table 2--World: Per capita income and meat and grain consumption, 1962 estimate

| Per capita income | Meat | Grain | | | Income elasticity | | Grain to meat ratio 1/ | Feed grain share 2/ |
|---|---|---|---|---|---|---|---|---|
| | | Food | Feed | Both | Meat | Grain | | |
| Dollar equivalent | Kilograms | | | | Rate | | | Percent |
| 25 | 0 | 48.8 | 0 | 48.8 | z | 0.84 | 0 | 0 |
| 50 | 0 | 117.8 | 0 | 117.8 | z | .32 | 0 | 0 |
| 75 | 5.2 | 144.3 | 4 | 148.3 | 3.41 | .15 | .7 | 0 |
| 100 | 9.8 | 156.5 | 13 | 169.5 | 1.50 | .07 | 1.3 | 2 |
| 125 | 12.9 | 164.3 | 22 | 186.3 | 1.02 | .01 | 1.7 | 5 |
| 150 | 15.2 | 159.4 | 30 | 189.4 | .82 | -.02 | 1.9 | 8 |
| 200 | 18.7 | 154.7 | 44 | 198.9 | .65 | -.06 | 2.3 | 12 |
| 250 | 21.4 | 148.9 | 53 | 201.9 | .58 | -.09 | 2.5 | 15 |
| 300 | 23.8 | 142.8 | 63 | 205.8 | .56 | -.11 | 2.6 | 17 |
| 350 | 25.9 | 137.3 | 71 | 208.3 | .55 | -.12 | 2.7 | 19 |
| 400 | 27.9 | 132.1 | 79 | 211.1 | .56 | -.13 | 2.8 | 20 |
| 450 | 29.8 | 127.5 | 86 | 213.5 | .57 | -.14 | 2.9 | 22 |
| 500 | 31.6 | 123.3 | 102 | 225.3 | .63 | -.14 | 3.2 | 24 |
| 750 | 40.3 | 107.2 | 138 | 245.2 | .63 | -.16 | 3.4 | 30 |
| 1,000 | 48.6 | 96.2 | 173 | 269.2 | .68 | -.17 | 3.6 | 36 |
| 2,000 | 80.9 | 75.9 | 320 | 395.9 | .79 | -.18 | 4.0 | 57 |
| 3,000 | 112.8 | 61.4 | 484 | 545.4 | .85 | -.18 | 4.3 | 77 |

z = Infinity.
1/ Kilograms of grain fed per kilogram of meat produced.
2/ Feed in total grain consumption.

Sources: Main Sequence equations, appendix B, and (148).

In the following sections, the Main Sequence is invoked to quantify behavioral parameters for regions with poor data or for adjusting country estimates to the larger scale of regional requirements.

## WORLD MEAT DEMAND

Four meat commodity categories are identified in the World GOL Model and equations developed for them: beef (all bovine meat including buffalo and veal), pork (all pigmeat), poultry, and mutton (all sheep, lamb, and goat meat). The demand equations for meat commodities have the following general form, as illustrated by demand for beef:

```
Beef consumption = F (Price of:  + G (Income per capita
                      Beef            Population
                      Pork            Change in:
                      Poultry           Taste
                      Mutton)           Policy)
```

where F represents linear functions of variables that interact simultaneously within the GOL model, and G stands for functions, not necessarily linear, of variables whose values are fixed before solving the model. Here, the F-functions are the direct price of beef and prices of other meats. The G-functions include per capita income and population separately to handle a larger latitude of projection assumptions, though multiplied by each other they define total income. Assumptions about changes of taste, in policies, or in institutional arrangements are also handled as G-functions.

The World GOL Model could not be fitted econometrically because of the large number of coefficients involved. Instead, the existence of numerous statistical estimations of recent years was recognized. Empirical studies from around the world were analyzed and coefficients chosen for incorporation into the model to serve as guides. Results of a number of such studies are evaluated and summarized here, with a focus on meat and regions which are significant in the world commercial meat economy. This section draws on the work of Mielke (138), especially in relation to the European Community and Japan. Before turning to the regional survey, a theoretical issue must be faced.

### Changing Demand Elasticities

The question arises as to whether demand elasticities change systematically through time in such a way that special allowance should be made in the design of projection models for the changes that might occur. Plausible arguments can be made on both sides.

It can be argued that demand-price elasticities for meat tend to be high when incomes are low because (1) consumers with limited budgets are extremely price sensitive, and (2) meat tends to be a preferred, more expensive food compared to cereals, even to low income consumers. Conversely, as incomes rise and consumers are more affluent, the budget constraint is reduced considerably and the price for meat is less important in determining consumption patterns. Thus, one might expect lower values of demand-price elasticities in circumstances of higher incomes.

However, contrary tendencies may also operate. The availability of substitutes affects price elasticities, increasing the values of elasticities as substitutes become available. Increasing availability may arise from three principal sources:

(1) new technology giving rise to new substitute products, (2) reductions of trade barriers to increase availability of substitutes via increasing trade, and (3) the rise, with rising income, of the increasingly important commercial marketing sector which replaces individual price responses with the acute, institutionalized price sensitivity of business.

The material presented here is inconclusive. The Main Sequence equations referred to above and presented in appendix B leave intact the hypothesis that meat, grain, and feed demand functions are worldwide in scope and central tendency as to price response. This is a notable result considering the multiplicity of geographic, climatic, and cultural circumstances which these functions serve to summarize. The Main Sequence calculations constitute evidence for stability of the structural forms of the world demand for meat.

Tables 3, 4, and 5 summarize demand calculations made for Germany, Japan, and Norway, respectively. Investigators in these three countries have analyzed the question of changing demand elasticities through time, using econometric techniques applied to their own data. The results for Germany are inconclusive, because of the lack of uniformity of method employed by the various researchers whose work is summarized. The German researchers, Plate, especially (1055, 1056), claim to perceive a decline of the order of one-half in the income elasticities applicable to meats in Germany from the early 1950's to the late 1960's. They make no such claim with respect to price elasticities.

An attempt was made to test whether price elasticities are changing in a measurable way in Germany. To do this, the null hypothesis was set up that meat demand functions are not changing. Mielke (138) reran some of Kost's equations (136) with dummy variables added to allow the regression coefficients to take on separate values for recent and for early years into which the total data period was divided. The results from this analysis did not challenge the null hypothesis. They did not produce evidence that demand functions are changing. While results in the table suggest that price elasticities were apparently decreasing in the last two decades, this appearance may not be real, given the difficulty in evaluating the methodologies used and the failure to measure statistically such possible change using Kost's data.

Evidence for changing demand income and price elasticities in Japan is presented in table 4. Evaluating the periods 1955-62 and 1963-70, the results from a recent study (1035) show that except for pork, the demand price elasticities are higher in the more recent period. This is not surprising, since, of all meats, pork is more of a mainstay in Japanese consumption patterns and, thus, probably more accessible to measurement and stability in statistical response. It is the only meat whose price coefficients were statistically significant in the earlier period. Given the property of least squares regressions that the coefficient tends to zero as the level of its statistical significance is reduced, the low price elasticities shown for the earlier period may well be due to lack of effective measurement. Thus, it is difficult to conclude that demand-price elasticities have increased in Japan. This conclusion is reinforced by the presence of import quotas for beef.

The evidence for changing demand elasticities in Norway covers the period from 1930 to 1959, omitting the years 1940-48. In the rising and falling of the statistical coefficients, one suspects the presence of an underlying pattern throughout which the statistical technique is attempting to identify and quantify. The source (1003) includes a table of statistical errors not reproduced here. The evidence for systematic change in demand elasticities in Norway is inconclusive.

Table 3--Germany: Demand elasticities for meat

| Commodity and timespan | Price elasticity: Beef | Price elasticity: Pork | Price elasticity: Poultry | Income elasticity |
|---|---|---|---|---|
| Beef: | | | | |
| 1950-62 | -0.84 to -0.93 | 0.17 to 0.23 | 0.11 to 0.13 | 0.95 to 1.01 |
| 1955-65 | -.66 to -.84 | .15 to .25 | -- | .63 to .77 |
| 1955-68 | -.60 | .36 | -- | .45 |
| 1960-69 | -.60 | -- | -- | .55 |
| Pork: | | | | |
| 1950-62 | .12 to .13 | -.70 to -.72 | -.02 | .53 to .58 |
| 1955-65 | .06 to .13 | -.17 to -.45 | .11 | .33 to .40 |
| 1955-68 | .24 | -.59 | -- | .47 |
| 1960-69 | .30 | -.55 | -- | .30 |
| Poultry: | | | | |
| 1950-62 | .23 to .36 | 1.26 to 1.28 | -2.46 to -2.67 | 1.31 to 1.44 |
| 1955-65 | -- | -- | -1.55 to -1.94 | .40 to 1.39 |
| 1955-68 | -- | -- | -.44 | .99 |
| 1960-69 | -- | -- | -.80 | .50 |

-- = Not applicable.

Sources: Time span 1950-62 (1064), 1955-65 (1042), 1955-68 (136), and 1960-69 (1056).

Table 4--Japan: Demand elasticities for meat

| Commodity and timespan | Income elasticity: Low | Income elasticity: High | Direct-price elasticity: Low | Direct-price elasticity: High |
|---|---|---|---|---|
| Beef: | | | | |
| 1955-62 | 1.13 | 1.27 | -0.94 | -1.06 |
| 1963-70 | .89 | .97 | -1.76 | -1.78 |
| Pork: | | | | |
| 1955-62 | 1.77 | 2.98 | -1.27 | -2.15 |
| 1963-70 | 1.24 | 1.79 | -1.27 | -1.95 |
| Chicken: | | | | |
| 1955-62 | 1.71 | 2.72 | - .12 | - .22 |
| 1963-70 | .56 | 1.24 | -1.31 | -3.09 |
| All meat, including whale: | | | | |
| 1955-62 | 1.31 | 1.43 | - .35 | - .77 |
| 1963-70 | 1.08 | 1.13 | - .53 | - .73 |

Sources: (1035 and 1036).

Table 5--Norway: Demand elasticities for food from time series regression 1/

| Commodity | Expenditure elasticity | | | | Direct-price elasticity | | | |
|---|---|---|---|---|---|---|---|---|
| | 1930-39 | 1930-59 | 1949-59 | 1953-59 | 1930-39 | 1930-59 | 1949-59 | 1952-59 |
| Meat: | | | | | | | | |
| Fresh | -- | -- | 0.7 | 0.7 | -- | -- | -0.2 | 0.1 |
| Canned | -- | -- | 2.0 | 5.9 | -- | -- | -2.2 | .4 |
| Fish: | | | | | | | | |
| Fresh | 0.2 | 0.3 | .8 | 1.1 | -0.4 | -0.5 | -.9 | -.5 |
| Canned dinner | -- | -- | -.2 | -.1 | -- | -- | .8 | -.2 |
| Other canned | -- | -- | -2.0 | .2 | -- | -- | .9 | -.6 |
| Eggs | .8 | .6 | 1.0 | 1.2 | -.7 | -.4 | -.1 | -.3 |
| Milk: | | | | | | | | |
| Cream | .4 | .0 | -.9 | -.4 | .5 | .1 | .1 | -.1 |
| Condensed and powdered | .5 | -.1 | -1.2 | -1.6 | -1.3 | -2.6 | -2.0 | -1.9 |
| Cheese | 1.6 | .5 | .9 | -.5 | -1.3 | .2 | .3 | 1.2 |
| Butter | .2 | -.6 | -1.0 | -.5 | -1.0 | -.4 | -.4 | -.9 |
| Margarine | .7 | .7 | 1.1 | .6 | -.2 | .3 | .3 | -.1 |
| Flour | .5 | -.1 | -1.0 | -.2 | -.7 | -.8 | -.9 | -1.2 |
| Bread, etc. | 1.0 | .9 | -.5 | -.9 | -.1 | -.9 | -.1 | .2 |

-- = Not applicable. Excludes 1940-48.
1/ Data from 1930 to 1959, excluding the years 1940 to 1948.

Source: (1002).

## Demand Structure by Region

The purpose of this section is to clarify the regional structure of world demand for livestock products. In general, empirical studies used for this purpose are based on time-series data, although Denmark (1002 and 1003), France (1019 and 1020), Japan (1035 and 1036), and the United Kingdom (1038 and 1068) have contributed a growing list of literature on cross-sectional budget or diary analysis. Time-series studies before 1950 were not examined because of the lingering effects of market disruptions during World War II. In addition, more recent time periods would tend to reflect more appropriate demand responses for the period to be projected. In most cases, ordinary least squares techniques related per capita consumption to per capita income and prices. Income elasticities are readily available. Where price effects have been calculated, direct-price elasticities are at times the only ones found, while cross-price elasticities appear less frequently. Nevertheless, some instances have been found of full matrices of direct- and cross-price elasticities, notably by the Scandinavians (1001, 1003, and 1026), the British (414, 1038, and 1068), and the Japanese (1035 and 1036). Organizations such as the Food and Agriculture Organization of the United Nations (FAO) and the Organization for Economic Cooperation and Development (OECD) have estimated income elasticities for member countries (602, 603, 604, 605, 607, 608, 804, 805, 809, and 811), but have not published price elasticity estimates. Michigan State University (MSU) studies have concentrated on the European Community, the original six (EC-6) (301, 304, 305, 306, and 307) and the three new members (EC-3) (302). The United Nations Conference on Trade and Development (UNCTAD) (1001) and the European Community Commission (ECC) (1018) have sponsored studies which have been increasingly useful to the purposes for which the GOL model is intended.

### United States

The results of two studies of U.S. demand elasticities have been carefully evaluated in developing the elasticity coefficients incorporated into the GOL model and used along with calculations made especially for specifying the GOL model. Brandow (1012), working at Pennsylvania State University and applying the large system mathematical methods developed by Frisch (1022), calculated a tableau of price and income elasticities relating to agricultural commodities at both retail and farm levels in the mid-1950's. George and King (1024), at the University of California, prepared a similar tableau of elasticities evaluated in the mid-1960's. The coefficients pertaining to the demand for meats are presented in table 6. They serve as the starting point for quantification of demand relationships for the United States. Although shown together, the two demand matrices are not strictly comparable for several reasons: they are for different periods of time, they were prepared by different methodologies, and, though showing the same field of meat demand, they are taken from larger matrices of demand relationships of differing sizes (the Brandow matrix contains 25 commodity categories, and the George and King matrix, 50).

These reasons make it difficult to determine a theoretically superior tableau for the United States for the purpose of the GOL model. The differences between them depend upon more than the different times for which they were developed. George and King have calculated direct-price elasticities for different years which, in the case of meats, rise and fall through time. Thus, it becomes difficult to substantiate the argument that direct elasticities are systematically falling through time or that they are clearly functions of income levels.

Table 6--United States: Demand elasticities for meat by market, 1956 and 1965

| Market, year, and commodity | Price elasticity | | | | | | | Income elasticity |
|---|---|---|---|---|---|---|---|---|
| | Beef | Veal | Pork | Lamb and mutton | Chicken | Turkey | Non-food | |
| Retail: | | | | | | | | |
| 1956: | | | | | | | | |
| Beef | -0.950 | 0.057 | 0.100 | 0.040 | 0.075 | 0.008 | 0.155 | 0.470 |
| Veal | .378 | -1.600 | .185 | .073 | .138 | .013 | .190 | .577 |
| Pork | .134 | .037 | -.750 | .035 | .066 | .007 | .106 | .320 |
| Mutton | .620 | .170 | .415 | -2.350 | .215 | .021 | .215 | .650 |
| Chicken | .234 | .064 | .156 | .043 | -1.160 | .125 | .122 | .370 |
| Turkey | .100 | .027 | .065 | .018 | .500 | -1.404 | .162 | .490 |
| 1965: | | | | | | | | |
| Beef | -.644 | .028 | .083 | .045 | .068 | .008 | .100 | .290 |
| Veal | .359 | -1.718 | .198 | .066 | .174 | .014 | .203 | .591 |
| Pork | .076 | .014 | -.413 | .060 | .035 | .005 | .046 | .133 |
| Mutton | .589 | .066 | .891 | -2.626 | .234 | .015 | .196 | .571 |
| Chicken | .197 | .044 | .121 | .055 | -.777 | .084 | .061 | .178 |
| Turkey | .098 | .015 | .065 | .018 | .400 | -1.555 | .158 | .768 |
| Farm level: | | | | | | | | |
| 1965: | | | | | | | | |
| Beef | -.416 | -- | .048 | .029 | .052 | -- | -- | -- |
| Veal | .232 | -- | .115 | .042 | .134 | -- | -- | -- |
| Pork | .049 | -- | -.241 | .038 | .027 | -- | -- | -- |
| Mutton | .381 | -- | .520 | -1.670 | .181 | -- | -- | -- |
| Chicken | .127 | -- | .070 | .034 | -.602 | -- | -- | -- |
| Turkey | .063 | -- | .038 | .011 | .310 | -- | -- | -- |

-- = Not applicable.

Sources: Retail 1956, (1012); retail and farm level 1965, (1024).

Tables 7 and 8 show results of econometric estimation of U.S. demand elasticities using variable specification more nearly like that used in the design of the GOL model. There is evidence of instability of measurement of elasticities. But the evidence is ambiguous.

U.S. direct-price elasticities for meat are calculated below for various years.

| Commodity | 1955 | 1960 | 1963 | 1970 |
|---|---|---|---|---|
| Beef | -0.68 | -0.60 | -0.63 | -0.64 |
| Veal | -3.72 | -3.19 | -2.79 | -2.48 |
| Pork | -.45 | -.41 | -.43 | -.42 |
| Lamb and mutton | -1.79 | -1.79 | -2.15 | -2.15 |
| Chicken | -.42 | -.55 | -.57 | -.60 |

Source: (1024).

Working with Stone in the United Kingdom, Tobin (1066) developed a demand function for food in the United States. Published in 1950, its results are dated, but the study is a clear example of the method of conditional regression using *a priori* knowledge of income response from cross-sectional studies.

Canada

The following meat demand elasticities for Canada show a commodity arrangement which is different from that employed in the GOL model.

| Commodity | Price elasticity | | | | | Income Elasticity |
|---|---|---|---|---|---|---|
| | Beef | Veal | Lamb | Pork | Poultry | |
| Beef | -0.52 | -- | 0.05 | 0.16 | -- | 0.84 |
| Veal | -- | -1.400 | .51 | -- | .26 | .45 |
| Lamb | -- | -- | -1.80 | -- | .14 | -2.91 |
| Pork | .28 | .650 | .28 | -1.05 | -- | 0 |
| Poultry | -- | .004 | -- | -- | -.09 | 1.13 |

-- = Not applicable.
Source: (1067).

This is suggestive of the sort of commodity interplay that was given up for this country, and for others, in adopting that used in GOL. Especially interesting is the importance of veal and lamb as separate categories and the central role played by the lamb price in the other demand equations.

Table 7--United States: Demand elasticities for agricultural commodities from regression

| Equation and commodity | Demand-price elasticity: Beef | Pork | Poultry | Eggs | Income elasticity |
|---|---|---|---|---|---|
| Price-dependent: | | | | | |
| Beef | -0.61 | -- | -- | -- | 0.73 |
| Pork | .56 | -0.83 | -- | -- | .29 |
| Poultry | .74 | -- | -1.72 | -- | .52 |
| Eggs | -- | -- | -- | -0.36 | .30 |
| Quantity-dependent: | | | | | |
| Beef | -.52 | -- | -- | -- | .72 |
| Pork | .49 | -.75 | -- | -- | .24 |
| Poultry | .29 | -- | -.83 | -- | .92 |
| Eggs | -- | -- | -- | -.15 | .52 |

-- = Not applicable.

Source: (132).

Table 8--United States: Range of calculated demand elasticities for agricultural commodities

| Equation and commodity | Direct-price elasticity | | Equation statistics 1/ | | Income elasticity | |
|---|---|---|---|---|---|---|
| | Low | High | $R^2$ | DW | Low | High |
| Price-dependent: | | | | | | |
| Beef | -0.59 | -0.64 | 0.86 | 1.83 | 0.70 | 0.75 |
| Pork | -.80 | -.85 | .94 | 1.78 | .28 | .33 |
| Poultry | -1.61 | -1.85 | .89 | 1.91 | .51 | .52 |
| Eggs | -.33 | -.39 | .72 | 1.69 | .25 | .30 |
| Quantity-dependent: | | | | | | |
| Beef | -.51 | -.54 | .98 | 2.10 | .70 | .74 |
| Pork | -.72 | -.77 | .90 | 1.66 | .23 | .26 |
| Poultry | -.77 | -.90 | .98 | 2.38 | .90 | .94 |
| Eggs | -.13 | -.16 | .87 | .63 | .48 | .54 |

1/ $R^2$ = coefficient of multiple determination. DW = Durbin-Watson statistic.

Source: (132).

## North America

Although not a separate region in the World GOL Model, North America is shown (table 9) because its authors have made similar calculations of food-demand elasticities for other regions of the world. The authors are associated with both the FAO and the UNCTAD. Comparisons among the regional patterns calculated and with the GOL regional patterns serve to identify both similarities and differences among the diverse regions. As defined here, North America includes the United States and Canada.

## European Community

Most econometric work on the European Community (EC), whether on the original six continental members (EC-6) or on the new member countries (EC-3), has been carried out on an individual country basis. Some aggregate analysis carried out by ESCS is included in table 10.

Significant work in Germany is being done at the universities. The work by Langen (1042), building on Stamer and Worffram (1064), is especially noteworthy, along with Plate (1055 and 1056) for his studies on the marketing of agricultural products.

France has benefitted from analysis of both time series and family budget surveys and diaries. Work at the Centre de Recherche et de Documentation sur la Consommation (CREDOC) utilized here has produced conditioned regression estimates of demand elasticities based on time series analysis in which income elasticities were introduced *a priori* from budget studies (407). Work by Fouquet (1020) at the Institute National de la Statistique de des Estudes Economiques (INSEE) has also been utilized. ESCS work has been relied upon in the cases of both Germany and France.

Italy has produced some controversial analytical studies. One of these, by Cao-Pinna (405), has been re-analyzed and the demand elasticities computed at the regression means. It should be noted that continuous inflation over three decades has made confident price analysis hazardous throughout the countries of the European Community.

The United Kingdom has routinely conducted household surveys (1068) on an annual basis and has published demand elasticity measures as a result of this work. Time-series analysis and conditioned regression have also been done based on the surveys. Ferris and Josling and others at Michigan State University (302) and the University of London also calculated demand elasticities for the United Kingdom, but obtained considerably different values for roughly the same time periods.

The work of the Agricultural Economics Research Institutes in both Belgium (1060 and 1070) and the Netherlands (1052) has been used, as well as of several universities, notably Antwerp (418), Aarhus (401), and Oxford (406 and 414). The following demand elasticities from regression for Belgium were developed from Antwerp:

| Commodity | Direct-price elasticity | Income elasticity | $R^2$ |
|---|---|---|---|
| Meat | -0.82 | 1.09 | 0.98 |
| Milk | -.40 | .75 | .96 |
| Cheese | -.58 | 1.00 | .92 |
| Butter | +.52 | -.45 | .79 |
| Bread | -.37 | -.22 | .83 |
| Total food | -.51 | -.59 | .98 |

Demand elasticities for Denmark are shown in table 11.

Table 10 shows demand elasticities for each of the EC countries. The elasticities are approximate averages of the elasticities reported in the several studies if more than one study is reported for a given country. To point up diversities encountered, two sets of coefficients are shown for the United Kingdom.

In table 12, demand elasticity matrices are presented for the two groups of countries constituting the European Community, EC-6 and EC-3. An approximate weighting of these to form a composit for the enlarged European Community (EC-9) is also presented. While weighted averages of individual countries are used for the EC-6, the United Kingdom dominates the new member group. Elasticities are synthesized more in line with the Michigan State University's income elasticities while adapting price elasticities from the British National Food Survey (1068).

Projection studies by the member countries contain demand price and income elasticities used by the EC Commission for its formal projections. These are summarized in table 13; they are presented for comparative purposes and as a reference in developing further generations of the World GOL Model.

## Other Western Europe

Other Western Europe has been closely modeled upon studies describing the EC-6. It is a fragmented region scattered about the periphery of the EC-6. Demand elasticities are shown separately in table 14 for Austria, Spain, and Sweden. Elasticities for Norway were presented in table 5 in connection with the possibility of changing elasticities.

## Western Europe

Although Western Europe in its entirety is not specified as a GOL region, table 15 by the FAO and UNCTAD authors is presented for comparative purposes and for showing the meat complex in the more comprehensive food context. It is useful for making comparison with EC specifications and with U.S. elasticities.

Table 9--North America: Demand elasticities for agricultural commodities

| Commodity | Price elasticity | | | | | | | | | Income elasticity |
|---|---|---|---|---|---|---|---|---|---|---|
| | Bread grain | Rice | Sugar | Meat | Eggs | Milk | Vegetable oils | Food | Non-food | |
| Bread grain | -0.34 | 0.08 | 0.01 | 0.08 | 0.01 | 0.01 | 0.03 | 0.26 | -0.06 | -0.20 |
| Rice | .03 | -2.54 | 0 | .01 | .28 | 1.45 | .51 | -.26 | .06 | .20 |
| Sugar | 0 | 0 | -.04 | .02 | 0 | .02 | 0 | .00 | .00 | .00 |
| Meat | .01 | .01 | 0 | -.57 | .20 | .09 | 0 | -.26 | .06 | .20 |
| Eggs | .03 | .01 | 0 | .04 | -1.70 | 1.57 | .18 | .13 | -.03 | -.10 |
| Milk | .05 | .01 | 0 | .08 | .14 | -.34 | .16 | .26 | -.06 | -.20 |
| Vegetable oils | .02 | .02 | 0 | .15 | .07 | .35 | -1.60 | -.13 | .03 | .10 |
| Food | .01 | .00 | .00 | -.14 | .01 | .05 | -.01 | -.42 | .02 | .06 |
| Nonfood | -.00 | -.00 | -.01 | -.04 | -.01 | -.02 | .00 | -.08 | -1.00 | 1.08 |
| Expenditure proportion | .00 | .00 | .01 | .05 | .01 | .02 | .00 | .08 | .92 | 1.00 |

Source: (1001).

Table 10--European Community: Demand elasticities for meat and fish, member countries

| Country and commodity | Price elasticity: Beef | Pork | Poultry | Mutton | All meat | Fish | Income elasticity |
|---|---|---|---|---|---|---|---|
| Germany, Federal Republic: | | | | | | | |
| Beef | -0.75 | 0.25 | 0.10 | -- | -- | -- | 0.70 |
| Pork | .13 | -.59 | .11 | -- | -- | -- | .47 |
| Poultry | .60 | 1.00 | -0.50 | -- | -- | -- | .90 |
| All meat | -- | -- | -- | -- | -0.36 | -- | .58 |
| France: | | | | | | | |
| Beef | -.80 | .32 | -- | -- | -- | -- | .60 |
| Pork | .30 | -.55 | -- | -- | -- | -- | .62 |
| Poultry | .20 | .20 | -.67 | -- | -- | -- | .70 |
| Italy: | | | | | | | |
| Beef | -.45 | .31 | .05 | -- | -- | -- | 1.33 |
| Pork | 1.59 | -1.66 | .15 | -- | -- | -- | .78 |
| Poultry | .30 | .10 | -1.00 | -- | -- | -- | 1.20 |
| Netherlands: | | | | | | | |
| Beef | -.55 to -.60 | -- | -- | -- | -- | -- | .60 to .65 |
| Belgium: | | | | | | | |
| Meat | -- | -- | -- | -- | -.82 | -- | 1.09 |
| Denmark: | | | | | | | |
| Beef | -.90 | .23 | .06 | -- | -- | -- | .65 |
| Pork | .34 | -1.36 | .09 | -- | -- | -- | .49 |
| Poultry | .30 | .55 | -.30 | -- | -- | -- | .51 |
| All meat | -- | -- | -- | -- | -.57 | .47 | .26 |
| Fish | -- | -- | -- | -- | -- | -1.85 | .72 |
| United Kingdom: | | | | | | | |
| National Food Survey | | | | | | | |
| Beef | -.79 | .05 | .08 | -0.35 | -- | -- | .10 |
| Pork | .18 | -1.21 | .18 | .17 | -- | -- | .31 |
| Poultry | .38 | .20 | -.35 | -.66 | -- | -- | .53 |
| Mutton | -.61 | .08 | -.26 | .25 | -- | -- | .21 |
| Michigan State University | | | | | | | |
| Beef | -2.49 | .52 | -- | .72 | -- | -- | .71 |
| Pork | .74 | -2.37 | -- | .61 | -- | -- | .61 |
| Poultry | -- | -- | -.24 | -- | -- | -- | .79 |
| Mutton | .58 | .26 | -- | -1.35 | -- | -- | .09 |
| EC-6: | | | | | | | |
| All meat | -- | -- | -- | -- | -.32 | -- | .71 |

-- = Not applicable.

Sources: Germany (1042, 1055, 1064 and 136); France (407, 1020, and 136); Italy (113 and 405); Netherlands (416); Belgium (418); Denmark (401); United Kingdom (302) and (1068); and EC-6 (145). Compare also (307) for demand elasticities for France-Belgium, Germany-Netherlands, and Italy.

Table 11--Denmark: Demand elasticities for agricultural commodities and fish from regression

| Commodity | Price elasticity | | | | | | | | | | Income elasticity |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | Average | | | |
| | Beef | Pork | Poultry | Meat | Fish | Eggs | Cheese | Pork-poultry | Beef-poultry | Beef Poultry | |
| Beef | -1.06 | -- | -- | -- | -- | -- | -- | 0.42 | -- | -- | 0.70 |
| Pork | -- | -1.31 | -- | -- | -- | -- | -- | -- | 0.40 | -- | .49 |
| Poultry | -- | -- | -0.31 | -- | -- | -- | -- | -- | -- | 1.09 | .30 |
| Meat | -- | -- | -- | -0.59 | 0.39 | -- | -- | -- | -- | -- | .28 |
| Fish | -- | -- | -- | .04 | -1.87 | -- | -- | -- | -- | -- | .71 |
| Eggs | -- | -- | -- | -- | -- | -0.07 | -- | -- | -- | -- | 1.07 |
| Cheese | -- | -- | -- | -- | -- | -- | -0.93 | -- | -- | -- | 1.28 |

-- = Not available.

Sources: (1003 and 401).

Table 12--European Community: Demand elasticities for meat, by region

| Region and commodity | Price elasticity | | | | | Income elasticity |
|---|---|---|---|---|---|---|
| | Beef | Pork | Poultry | Mutton | All meat | |
| EC-6: | | | | | | |
| Beef | -0.7 | 0.3 | 0.1 | -- | -- | 0.6 |
| Pork | .5 | -.8 | .12 | -- | -- | .5 |
| Poultry | .38 | .5 | -1.07 | -- | -- | 1.0 |
| Mutton | .15 | .15 | -- | -0.25 | -- | 0 |
| All meat | -- | -- | -- | -- | -0.35 | .73 |
| EC-3: | | | | | | |
| Beef | -.79 | .2 | .08 | -.35 | -- | .7 |
| Pork | .18 | -.8 | .2 | .17 | -- | .6 |
| Poultry | .3 | .3 | -.6 | -- | -- | 1.0 |
| Mutton | -.61 | .08 | -.26 | .25 | -- | 0 |
| EC-9: | | | | | | |
| Beef | -.73 | .22 | .1 | -.12 | -- | .62 |
| Pork | .42 | -.8 | .2 | .04 | -- | .52 |
| Poultry | .38 | .45 | -.95 | -- | -- | 1.00 |
| Mutton | -.42 | .01 | -- | -.12 | -- | 0 |

-- = Not applicable.

Source: Judgmental weighting of elasticities shown in table 10. Compare these figures with those in table 13, obtained after the World GOL Model had become operational.

Table 13--European Community: Demand elasticities for agricultural commodities and fish used by the EC Commission in agricultural projections to 1977

| Country and commodity | Price elasticity | | | | | | | | Income elasticity |
|---|---|---|---|---|---|---|---|---|---|
| | Beef | Pork | Poultry | Mutton | Fish, fresh | Fish, canned | Direct price | Eggs | |
| Germany, Federal Republic: | | | | | | | | | |
| Beef | -0.75 | 0.23 | -- | -- | -- | -- | -- | -- | 0.69 |
| Pork | .13 | -.45 | -- | -- | -- | -- | -- | -- | .37 |
| Poultry | .58 | .96 | -1.62 | -- | -- | -- | -- | -- | .84 |
| Meat | -- | -- | -- | -- | -- | -- | -0.37 | -- | .57 |
| Eggs | -- | -- | -- | -- | -- | -- | .17 | -0.47 | .27 |
| France: | | | | | | | | | |
| Beef | -.62 | -- | -- | -- | -- | -- | -- | -- | .40 |
| Veal | -- | -- | -- | -- | -- | -- | -1.00 | -- | .79 |
| Pork, fresh | -- | -.20 | -- | -- | -- | -- | -- | -- | .20 |
| Ham | -- | -- | -- | -- | -- | -- | -.77 | -- | .76 |
| Poultry | -- | -- | -- | -- | -- | -- | -- | -- | .11 |
| Mutton | -- | -- | -- | -0.71 | -- | -- | -- | -- | .90 |
| Horse | -- | -- | -- | -- | -- | -- | -- | -- | -.23 |
| Fish, fresh | -- | -- | -- | -- | -0.07 | -- | -- | -- | .35 |
| Fish, canned | -- | -- | -- | -- | -- | -- | -- | -- | .86 |
| Meat | -- | -- | -- | -- | -- | -- | -.67 | -- | .55 |
| Italy: | | | | | | | | | |
| Beef | -1.00 | -- | -- | -- | -- | -- | -- | -- | 1.10 |
| Pork | 1.50 | -1.00 | 1.00 | -- | -- | -- | -- | -- | 1.00 |
| Poultry | 1.00 | -- | -2.00 | -- | -- | -- | -- | -- | 2.00 |
| Fish, fresh | -- | -- | -- | -- | -.30 | 0.30 | -- | -- | .70 |
| Fish, canned | -- | -- | -- | -- | -- | -.65 | -- | -- | .30 |
| United Kingdom: | | | | | | | | | |
| Beef I | -.84 | .17 | -- | -- | -- | -- | -- | -- | .02 |
| Beef II | -1.58 | .63 | -- | -- | -- | -- | -- | -- | 1.75 |
| Pork | -- | -1.13 | -- | .55 | -- | -- | -- | -- | 1.15 |
| Poultry | -- | -- | -1.23 | .95 | -- | -- | -- | -- | -- |
| Bacon I | -- | -- | -- | -- | -- | -- | -.60 | -- | .92 |
| Bacon II | -- | -- | -- | -- | -- | -- | -.58 | -.05 | .84 |
| Mutton | -1.19 | .91 | .36 | -- | -- | -- | -- | -- | .65 |
| Meat | -- | -- | -- | -- | .12 | -- | -.51 | -- | .20 |
| Ireland: | | | | | | | | | |
| Beef | -0.56 | -- | -- | -0.44 | -- | -- | -- | -- | 0.95 |
| Pork | -- | -2.51 | -- | .24 | -- | -- | -- | -- | -.25 |
| Poultry | -- | -- | -- | -- | -- | -- | -- | -- | 2.24 |
| Bacon | -- | -1.05 | -- | -- | -- | -- | -- | 0.75 | .17 |
| Mutton | -- | .64 | -- | -.89 | -- | -- | -- | -- | .65 |
| Meat | -- | -- | -- | -- | 0.24 | -- | -0.22 | -- | .78 |
| Eggs | -- | -.15 | -- | -- | -- | -- | -- | -- | -.82 |
| Denmark: | | | | | | | | | |
| Beef | -1.10 | .10 | -- | -- | -- | -- | -- | -- | .70 |
| Pork | .30 | -.60 | -- | -- | -- | -- | -- | -- | -.30 |
| Poultry | -- | -- | -0.60 | -- | -- | -- | -- | -- | .80 |
| Meat | -- | -- | -- | -- | .30 | -- | -.20 | -- | .03 |
| Fish | -- | -- | -- | -- | -- | -- | -- | -- | 1.00 |

-- = Not applicable.

Source: (1018).

Table 14--Other Western Europe: Demand elasticities for livestock and fish

| Country and commodity | Price elasticity | | | | | Income elasticity |
|---|---|---|---|---|---|---|
| | Beef | Veal | Pork | Poultry | Direct price | |
| Austria: | | | | | | |
| Beef | -0.24 | -- | -- | -- | -- | 0.58 |
| Veal | -- | -0.57 | -- | -- | -- | .58 |
| Pork | -- | -- | -0.07 | -- | -- | .82 |
| Poultry | 2.04 | -- | -- | -1.37 | -- | 1.68 |
| Meat | -- | -- | -- | -- | -1.26 | .66 |
| Spain: | | | | | | |
| Beef | -.59 | -- | -- | -- | -- | 1.50 |
| Pork | -- | -- | -.20 | -- | -- | .35 |
| Mutton | -- | -- | -- | -- | -.64 | .29 |
| Red meat | -- | -- | -- | -- | -.60 | .88 |
| Poultry | -- | -- | -- | -.77 | -- | 1.48 |
| Eggs | -- | -- | -- | -- | -1.97 | 1.79 |
| Fish | -- | -- | -- | -- | -.39 | .05 |
| Sweden: | | | | | | |
| Beef | -.8 | -- | .5 | -- | -- | .50 |
| Veal | -- | -1.0 | -- | -- | -- | .40 |
| Pork | .3 | -- | -.7 | -- | -- | .30 |

-- = Not applicable.

Sources: Austria (403), Spain (422), and Sweden (1065).

Table 15--Western Europe: Demand elasticities for agricultural commodities

| Commodity | Price elasticity | | | | | | | | | Income elasticity |
|---|---|---|---|---|---|---|---|---|---|---|
| | Bread grain | Rice | Sugar | Meat | Eggs | Milk | Vegetable oils | Food | Nonfood | |
| Bread grain | -0.34 | 0.08 | 0.01 | 0.08 | 0.01 | 0.01 | 0.03 | 0.26 | -0.06 | -0.20 |
| Rice | .03 | -3.00 | .12 | .01 | .18 | .26 | 2.15 | -.26 | .06 | .20 |
| Sugar | .24 | 0 | -.67 | .02 | 0 | .02 | 0 | -.39 | .09 | .30 |
| Meat | .01 | .01 | 0 | -.83 | .20 | .09 | 0 | -.52 | .12 | .40 |
| Eggs | .33 | 0 | 0 | .04 | -1.97 | .90 | .18 | -.52 | .12 | .40 |
| Milk | .16 | 0 | 0 | .08 | .11 | -.77 | .16 | -.26 | .06 | .20 |
| Vegetable oils | .02 | .02 | 0 | .15 | .11 | .35 | -2.18 | -.26 | .06 | .20 |
| Food | .03 | 0 | -.03 | -.18 | -.04 | -.07 | -.01 | -.45 | -.07 | .23 |
| Nonfood | -.04 | 0 | -.01 | -.04 | -.01 | -.04 | -.01 | -.15 | -1.01 | 1.17 |
| Expenditure proportion | .03 | 0 | .01 | .06 | .01 | .05 | .01 | .18 | .82 | 1.00 |

Source: (1001).

### Japan

Three studies of Japan are important to the GOL model. The first is an analytical study of food consumption conducted by the Japanese Ministry of Agriculture (1035 and 1036). Both cross-sectional and time-series approaches are used. The study used in preparation of the GOL model includes a long list of regressions which have been calculated for various time periods (see table 4).

The two other studies are by Filippello (118 and 119). The first of these is a doctoral dissertation in the form of a detailed analysis of the feed-livestock sector of Japan. The second contains a synthesized demand elasticity matrix for projection of the values of the feed-livestock sector of Japan. The synthesized estimates of demand elasticities are shown in tables 16 and 17. For projection, care has been taken to fix elasticity coefficients sufficiently high to overcome the persistent recent tendency to under estimate Japanese economic processes.

A more recent study of Japanese demand is shown in table 18 for comparative purposes. These results should be compared with the work of Barse (104) which projects Japan's future.

### Other Regions

The econometric analysis that has been performed on the feed-livestock economies of the United States, the European Community, Japan, and other parts of Western Europe, together with the equations describing the world's Main Sequence of meat, grain, and feed, have served as a basis for quantifying parameters for other regions of the world. Particularly useful to the quantification of demand relationships are the implications of the first Main Sequence equation, the world meat demand function with a price elasticity coefficient of -0.6 and an income elasticity of +0.6. Since the price coefficients found for the countries and regions of the developed and less developed world are of this order of magnitude, the procedure adopted for the GOL model has been to employ demand coefficients of this order of magnitude or less for the regions not yet analytically described by empirical econometric analysis.

Eastern Europe.--The authors of the FAO and UNCTAD studies also have calculated food demand matrices for Eastern Europe. These are shown in (table 19) for comparative purposes with Western Europe, the EC, and North America, and for providing a basis for quantifying further generations of the GOL model.

Oceania.--Australia is relied upon for modeling of Oceania's meat sector. Monash University is relied upon (table 20) for meat demand analysis. The university used a more comprehensive breakdown of certain meats than the GOL model, treating lamb and mutton separately, with resulting strong direct- and cross-price elasticities. New Zealand is the basis for modeling the Oceania dairy sector.

Argentina.--Price analysis in Argentina has been complicated for a number of decades by high inflation. The findings of two doctoral dissertations (1037 and 1053) are shown in tables 21 and 22 for the complex of variables which have been considered along with direct price and income in relation to beef consumption. The matrix of elasticities presented by the Instituto Nacional de Tecnologia Agropecuaria (INTA), and shown below, appears to be a reasonable summary of the meat demand structure of Argentina.

| Commodity | Price elasticity | | | | Income elasticity |
|---|---|---|---|---|---|
| | Beef | Pork | Poultry | Mutton | |
| Beef | -0.44 | -- | -- | -- | 0.37 |
| Pork | -- | -0.76 | -- | -- | .84 |
| Poultry | 1.95 | -- | -0.75 | -- | 0 |
| Mutton | -- | -- | -- | -0.18 | 0 |

-- = Not applicable.
Source: (402).

Brazil.--Demand and price analysis, for the purposes of developing such a world model as GOL, apparently is not far advanced in Brazil. The nation's economists are grappling with other problems, which to them have higher priority. Among these problems are determining the relative productivity of different production systems, determining the consumption effects of internal migration, measuring the effects of urbanization, and keeping analytically abreast of unexpected technological developments in hitherto minor or remote sectors. Work on demand-price analysis cannot be regarded as satisfactory from the viewpoint of modeling the World GOL Model. The Getulio Vargas Foundation (408, 409, 410 and 1032) has presented the work that must by relied upon.

Demand elasticities for Brazil from the Vargas Foundation's work are:

| Commodity | Income elasticity | | Substitution elasticity | |
|---|---|---|---|---|
| | Urban | Rural | Migration | Price 1/ |
| Beef | 0.64 | 0.27 | 0.04 | -0.18 |
| Pork | 1.02 | .40 | -.44 | .42 |
| Poultry | 1.31 | .33 | -.31 | 0 |
| Mutton | .24 | .16 | -.42 | -.47 |
| Fish | .80 | .07 | .05 | 2.86 |
| Eggs | .70 | .57 | -.10 | 2.70 |
| Milk | 1.00 | .56 | -.15 | 0 |

1/ Includes effects of both price and market limitation.
Sources: (408 and 409).

Table 16--Japan: Demand elasticities for meats and fish, 1965 and 1980 projection

| Year and commodity | Price elasticity | | | | | Income elasticity |
|---|---|---|---|---|---|---|
| | Beef | Pork | Poultry | Fish | Rice | |
| 1965: | | | | | | |
| Beef | -1.24 | 0.20 | 1.14 | 0.44 | -0.19 | 0.50 |
| Pork | .26 | -.72 | .17 | .09 | .18 | .72 |
| Poultry | .35 | .11 | -1.16 | .09 | .04 | .95 |
| 1980 Projection: | | | | | | |
| Beef | -.77 | .15 | .91 | .27 | -.10 | .64 |
| Pork | .14 | -.45 | .12 | .05 | .08 | .82 |
| Poultry | .20 | .08 | -.88 | .05 | .02 | 1.18 |

Sources: (118 and 119).

Table 17--Japan: Demand elasticities for meats used in projection

| Commodity category | Price elasticity | | | | Income elasticity |
|---|---|---|---|---|---|
| | Beef | Pork | Poultry | All meat | |
| Beef | -1.20 | 0.20 | 0.50 | -- | 1.20 |
| Pork | .26 | -.90 | .17 | -- | 1.10 |
| Poultry | .35 | .11 | -1.10 | -- | 1.20 |
| All meat | -- | -- | -- | -0.50 | 1.00 |

-- = Not applicable.

Source: Based on unpublished work by Nicholas A. Filippello underlying elasticities shown in table 16. Strong direct- and cross-price effects are used to compensate for systematic understatement of changes occurring in Japanese food consumption patterns.

Table 18--Japan: Demand elasticities for agricultural commodities and fish

| Commodity | Price elasticity | | | | | |
|---|---|---|---|---|---|---|
| | Rice | Other grain | Fish | Meat | Milk and eggs | Vege-tables |
| Rice | 0.33 | 0.01 | 0.02 | 0.01 | 0.01 | 0.02 |
| Other cereal | -.04 | -.19 | -.01 | 0 | 0 | -.01 |
| Fish | -.01 | 0 | -.06 | 0 | 0 | 0 |
| Meat | -.15 | -.02 | -.06 | -.76 | -.02 | -.04 |
| Milk and eggs | -.13 | -.02 | -.05 | -.01 | -.69 | -.04 |
| Vegetables | -.01 | 0 | -.01 | 0 | 0 | -.08 |
| Fruit | -.13 | -.02 | -.05 | -.01 | -.01 | -.04 |
| Commodity food | -.12 | -.02 | -.04 | -.01 | -.01 | -.04 |
| Other food | -.08 | -.01 | -.03 | -.01 | -.01 | -.03 |
| All food | 0 | -.02 | -.03 | -.07 | -.06 | -.02 |
| Nonfood | -.12 | -.02 | -.05 | -.01 | -.01 | -.04 |
| Expenditure proportion | .08 | .02 | .04 | .03 | .03 | .03 |

| Commodity | Price elasticity | | | | | Income elasti-city |
|---|---|---|---|---|---|---|
| | Fruit | Commodity food | Other food | All food | Non-food | |
| Rice | 0 | 0.01 | 0.04 | 0.44 | 0.13 | 0.57 |
| Other cereal | 0 | 0 | -.02 | -.28 | -.09 | .37 |
| Fish | 0 | 0 | -.01 | -.08 | -.03 | .11 |
| Meat | -0.01 | -.02 | -.10 | -1.17 | -.35 | 1.53 |
| Milk and eggs | -.01 | -.02 | -.09 | -1.06 | -.32 | 1.38 |
| Vegetables | 0 | 0 | -.01 | -.11 | -.03 | .15 |
| Fruit | -.69 | -.02 | -.09 | -1.07 | -.32 | 1.39 |
| Commodity food | -.01 | -.62 | -.08 | -.95 | -.29 | 1.23 |
| Other food | -.01 | -.01 | -.47 | -.65 | -.20 | .85 |
| All food | -.04 | -.05 | -.16 | -.44 | -.13 | .58 |
| Nonfood | -.01 | -.01 | -.08 | -.35 | -.92 | 1.27 |
| Expenditure proportion | .02 | .03 | .11 | .39 | .61 | 1.00 |

Source: (1062).

Table 19--Eastern Europe: Demand elasticities for agricultural commodities

| Commodity | Price elasticity | | | | | | | | | Income elasticity |
|---|---|---|---|---|---|---|---|---|---|---|
| | Bread grain | Rice | Sugar | Meat | Eggs | Milk | Vegetable oils | Food | Nonfood | |
| Bread grain | -.21 | 0.08 | 0.01 | 0.08 | 0.01 | 0.01 | 0.03 | 0 | 0 | 0 |
| Rice | .03 | -3.00 | .06 | .01 | .08 | -- | 2.56 | -.26 | .06 | .20 |
| Sugar | .15 | -- | -.58 | .02 | -- | .02 | -- | -.39 | .09 | .30 |
| Meat | .01 | .01 | -- | -.83 | .20 | .09 | -- | -.52 | .12 | .40 |
| Eggs | .20 | -- | -- | .04 | -2.10 | 1.21 | .13 | -.52 | .12 | .40 |
| Milk | .10 | -- | -- | .08 | .12 | -1.01 | .16 | -.26 | .06 | .20 |
| Vegetable oils | .02 | .02 | -- | .15 | .12 | .35 | -3.00 | -.26 | .06 | .20 |
| Food | -.01 | -.00 | -.03 | -.15 | -.03 | -.06 | -.01 | -.47 | .07 | .22 |
| Nonfood | -.08 | -.00 | -.01 | -.04 | -.01 | -.04 | -.00 | -.19 | -1.02 | 1.21 |
| Expenditure proportion | .06 | .00 | .02 | .07 | .01 | .05 | .01 | .21 | .79 | 1.00 |

-- = Not applicable.

Source: (1001).

Table 20--Australia: Demand elasticities for meat

| Commodity | Price elasticity | | | | | Income elasticity |
|---|---|---|---|---|---|---|
| | Beef | Lamb | Mutton | Pork | Meat | |
| Beef | -.79 | .39 | 0.04 | -- | -- | -0.09 |
| Lamb | .63 | -1.40 | .03 | -- | -- | .45 |
| Mutton | .82 | .10 | -1.02 | -- | -- | -.59 |
| Pork 1/ | - - - - - 1.10 - - - - - | | | -2.80 | -- | 1.40 |
| Meat | -- | -- | -- | -- | -0.20 | .20 |
| Meat | -- | -- | -- | -- | -- | .32 |

-- = Not applicable.
1/ Average price of beef, lamb, and mutton.

Source: (411).

Table 21--Argentina: Demand elasticities for beef 1/
(Annual)

| Commodity | Price elasticity | | | Income elasticity | | | Population | | Changes in CPI | Con- stant | $R^2$ DW |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Beef to CPI | Beef to food | Beef to non-food | Total | Wages | Non-wages | Level | Rural per-cent | | | |
| Beef | -0.547 (11.7) | -- | -- | -0.096 (.4) | -- | -- | 1.57 (9.8) | -- | -- | -8.63 (4.0) | 0.945 1.16 |
| Beef | -.565 (6.5) | -- | -- | -- | -0.117 (.8) | 0.126 (.7) | 1.55 (8.5) | -- | -- | 8.29 (3.8) | .945 .96 |
| Beef | -- | -0.152 (.3) | -0.367 (.9) | -- | -.142 (.9) | .139 (.7) | 1.49 (6.1) | -- | -- | -9.41 (3.6) | .942 .98 |
| Beef | -.567 (10.9) | -- | -- | -.427 (1.3) | -- | -- | -1.32 (1.2) | -2.71 (2.6) | 0.045 (2.6) | 15.16 (1.6) | .93 2.5 |

-- = Not applicable.
1/ Double logarithm regression equations using instrumental variables, where prices and income variables are in real terms, and t-statistics are reported in parentheses.

Source: (1037).

Table 22--Argentina: Demand elasticities for beef 1/
(Quarterly)

| Commodity and market | Price elasticity: Domestic: Beef | Price elasticity: Domestic: Fish | Price elasticity: Danish beef | Income elasticity: Domestic: Wages | Income elasticity: Importers: Trend | Foreign exchange real effective rate | Population | $R^2$ |
|---|---|---|---|---|---|---|---|---|
| Beef: | | | | | | | | |
| Domestic | -0.426<br>(9.7) | 0.067<br>(1.6) | -- | 0.346<br>(2.2) | -- | -- | 1.51<br>(5.6) | 0.89 |
| Export | -1.89<br>(3.8) | -- | 2.33<br>(2.6) | -- | 1.54<br>(1.1) | 1.73<br>(2.4) | -- | .70 |

-- = Not applicable.

1/ Elasticities calculated from 2-stage least squares regression equations, linear in the variables, and with t- statistics reported in parentheses.

Source: (1053).

Mexico and Central America.--The Mexican government appears to be highly interested in developing an understanding of institutional problems of agriculture and consumption that are in addition to those related to price. Mexican and Central American work on demand parameters is summarized here.

| Commodity | Income Elasticities | | |
|---|---|---|---|
| | Mexico | | Central America |
| | Urban | Rural | |
| Beef | 0.51 | 0.96 | 0.59 |
| Pork | .59 | .64 | .47 |
| Poultry | .76 | .90 | .77 |
| Mutton | .25 | 1.99 | 0 |
| Goat | .47 | 2.15 | 0 |
| Eggs | .51 | .69 | .69 |
| Milk | .41 | .80 | .34 |

Sources: Mexico (404, 603, and 1007); Central America (1008).

USDA investigators have calculated some demand elasticities for Mexico which are in harmony with the Main Sequence. John Link, for example, found a direct-price elasticity for meat consumption of about -0.6 with an income elasticity of about +0.3 for Mexico. With variables from 1956 to 1972 expressed as logarithms, oridinary least squares analysis gives the following meat demand equation:

$$\underset{}{BPC} = -\underset{(.1930)}{.6582}\ RPB + \underset{(.0447)}{.2735}\ RYPC + \underset{(.9792)}{3.3364} \qquad R^2 = .75,\ DW = 2.00$$

where BPC is beef consumption per capita in kilograms, RPB is the price index of cattle deflated by the index of consumer prices, and RYPC is per capita gross domestic product deflated by the index of consumer prices. Standard errors are shown in parentheses; $R^2$ is the coefficient of multiple determination; and DW is the Durbin-Watson statistic. Since computations are in logarithms, the regression coefficients are direct estimates of elasticities.

## World GOL Model Demand Elasticities

Demand elasticities incorporated into the World GOL Model are shown in table 23 for meat, and table 24 for dairy products. These elasticities are synthesized from all the material presented above. Adjustments are made for commodity and regional specification to conform to the requirements of the GOL model. For those regions with inadequate statistical bases of estimation to specify the required demand parameters, the Main Sequence is recalled and the regions are treated as part of a continuum of world demand. They are modeled in relation to regions with better known parameters.

Table 23--World GOL Model: Demand elasticities for meat, by country or region, 1970

| Country or region and commodity | Price elasticity | | | | | Income elasticity |
|---|---|---|---|---|---|---|
| | Beef | | Pork | Poultry | Mutton | |
| | Finished | Other | | | | |
| United States: | | | | | | |
| Beef, finished | -0.7 | 0.20 | 0.10 | -- | -- | 0.50 |
| Beef, other | .4 | -.80 | .10 | .10 | -- | .35 |
| Pork | .4 | -- | -.80 | .10 | -- | .25 |
| Poultry | .3 | -- | .20 | -1.00 | -- | .90 |
| Mutton | -- | -- | -- | -- | -- | -- |
| Canada: | | | | | | |
| Beef | -- | -.60 | .30 | .15 | -- | .70 |
| Pork | -- | .40 | -.70 | .15 | -- | .15 |
| Poultry | -- | .30 | .20 | -.80 | -- | .90 |
| Mutton | -- | -- | -- | -- | -- | -- |
| EC-6: | | | | | | |
| Beef | -- | .70 | .30 | .10 | -- | .60 |
| Pork | -- | .50 | -.80 | .12 | -- | .50 |
| Poultry | -- | .38 | .50 | -1.07 | -- | 1.00 |
| Mutton | -- | .15 | .15 | -- | -.25 | -- |
| EC-3: | | | | | | |
| Beef | -- | -.60 | .20 | .08 | -.20 | .70 |
| Pork | -- | .18 | -.80 | .20 | .17 | .45 |
| Poultry | -- | .30 | .30 | -.60 | -- | 1.00 |
| Mutton | -- | .40 | .10 | .20 | -.10 | -- |
| Other Western Europe: | | | | | | |
| Beef | -- | -.60 | .20 | .10 | -- | .70 |
| Pork | -- | .20 | -.70 | .20 | -- | .60 |
| Poultry | -- | .10 | .20 | -.80 | -- | .90 |
| Mutton | -- | .15 | .15 | -- | -.25 | -- |
| Japan: | | | | | | |
| Beef | -- | -1.20 | .26 | .35 | -- | 1.20 |
| Pork | -- | .20 | -.90 | .11 | -- | .90 |
| Poultry | -- | .50 | .17 | -1.10 | -- | .60 |
| Mutton | -- | -.40 | .20 | .30 | -.40 | .50 |
| Oceania: | | | | | | |
| Beef | -- | -.50 | -- | -- | .20 | -- |
| Pork | -- | .20 | -.40 | -- | -- | .10 |
| Poultry | -- | -- | -- | -- | -- | -- |
| Mutton | -- | .40 | -- | -- | -.80 | -- |

Continued

Table 23--World GOL Model: Demand elasticities for meat, by country or region, 1970--Continued

| Country or region and commodity | Price elasticity | | | | | Income elasticity |
|---|---|---|---|---|---|---|
| | Beef | | Pork | Poultry | Mutton | |
| | Finished | Other | | | | |
| Mexico and Central America: | | | | | | |
| Beef | -- | -.40 | .10 | -- | -- | .70 |
| Pork | -- | .10 | -.30 | -- | -- | .60 |
| Poultry | -- | -- | -- | -- | -- | -- |
| Mutton | -- | -- | -- | -- | -- | -- |
| Argentina: | | | | | | |
| Beef | -- | -.40 | -- | -- | -- | .30 |
| Pork | -- | .20 | -.40 | -- | -- | -- |
| Poultry | -- | -- | -- | -- | -- | -- |
| Mutton | -- | .20 | -- | -- | -.40 | -- |
| Brazil: | | | | | | |
| Beef | -- | .60 | .30 | -- | -- | .40 |
| Pork | -- | .20 | -.60 | -- | -- | .40 |
| Poultry | -- | -- | -- | -- | -- | -- |
| Mutton | -- | -- | -- | -- | -- | -- |

-- = Not applicable.

Sources:

United States--see text and tables 6, 7, and 8 citing (1012, 1024, and 132, and compare table 9, citing (1001), showing elasticities for North America;

Canada--see table 12 and sources cited, and compare sources for the United States;

European Community--see text, tables 10 and 12 and sources cited, and table 11, and compare table 13 and sources cited;

Other Western Europe--see tables 5 and 14 and sources cited, and table 15 showing elasticities for Western Europe, and compare table 9 showing elasticities for North America;

Japan--see tables 4, 16, 17, and 18 and sources cited;

Oceania--see table 20 and sources cited;

Mexico and Central America--see text and sources cited;

Argentina--see tables 21 and 22 and sources cited;

Brazil--see text and sources cited.

Table 24--World GOL Model: Demand elasticities for dairy products, by country or region, 1970

| Item | Price elasticity: Milk | Price elasticity: Butter | Price elasticity: Cheese | Income elasticity |
|---|---|---|---|---|
| United States: | | | | |
| Milk, fluid | -0.20 | -- | -- | -0.10 |
| Butter | -- | -0.70 | -- | -- |
| Cheese | -- | -- | -0.50 | .50 |
| Canada: | | | | |
| Milk, fluid | -.20 | -- | -- | -.10 |
| Butter | -- | -.70 | -- | -.30 |
| Cheese | -- | -- | -.50 | .60 |
| EC-6: | | | | |
| Milk, fluid | -.25 | -- | -- | .20 |
| Butter | -- | -.70 | -- | .20 |
| Cheese | -- | -- | -.60 | .50 |
| EC-3: | | | | |
| Milk, fluid | -.15 | -- | -- | .20 |
| Butter | -- | -.50 | -- | .20 |
| Cheese | -- | -- | -.60 | .30 |
| Other Western Europe: | | | | |
| Milk, fluid | -.20 | -- | -- | .30 |
| Butter | -- | -.50 | -- | .30 |
| Cheese | -- | -- | -.60 | .60 |
| Japan: | | | | |
| Milk, fluid | -.70 | -- | -- | .95 |
| Butter | -- | -.70 | -- | 1.00 |
| Cheese | -- | -- | -.169 | 1.25 |
| Oceania: | | | | |
| Milk, fluid | -.20 | -- | -- | .10 |
| Butter | -- | -.40 | -- | -.10 |
| Cheese | -- | -- | -.30 | .50 |

-- = Not applicable.

Source: See table 23 and sources cited.

### Longrun Demand Growth

Income elasticities for each region were developed with the price-elasticity matrix, since considerations of theoretical symmetry and homogeneity involve the entire set of elasticities, including those not specifically brought into the scheme of calculation. To the extent they can be foreseen, anticipated longrun effects have been incorporated into the demand equations through modifications to the set of income elasticities for each commodity. Other demand adjustments of a longrun nature are avoided.

## WORLD MEAT SUPPLY

As presently modeled, supply relationships in the World GOL Model livestock sector are based on direct- and cross-price elasticities for livestock commodities and a set of supply shifters, which are introduced as long term growth factors. Only market livestock commodities and their prices are now included in the variable field. Plans are being developed to increase the number of interacting variables to include livestock and slaughter numbers, slaughter weight or yield, and pasture or forage feed area.

The four meat commodity categories are those identified in connection with meat demand: beef, pork, poultry, and mutton. Additional meats, to achieve a comprehensive total, remain to be added later in the context of priorities for deepening the analysis of the livestock sector in a number of respects. An underlying production function is postulated for each region in the GOL model. Direct, competing, or joint production and input-to-product price effects are specified. The equations for the supply of meat have the following general form, as illustrated by the supply of pork:

```
Pork production = F (Product price of: + G (Productivity
                        Pork                 Technology
                        Beef                 Change in:
                        Poultry                Policy
                      Input price of:          Trend)
                        Corn
                        Oilmeal)
```

where F represents linear functions of variables that are endogenous to the GOL model, and G represents functions of exogenous variables whose values are projected before solving the interacting part of the model and which are not necessarily linear. Each of the products that has a price among the F-functions is provided with its own individual supply-demand specification. In the illustration above, pork output is provided for here to match against a pork demand equation from the meat demand sector. Tradeoff is provided for pork in relation to beef and poultry in terms of whether a high beef or poultry price will encourage or discourage more pork production or have a neutral effect. In any event, high prices of input feeds (corn and oilmeal) have a quantified inhibiting effect on pork production, whereas low feed prices constitute an encouragement. The exogenous G-functions take into account increases in productivity, growth in technology, and alterations in policies, such as relaxing or imposing production or marketing restrictions.

Much livestock supply analysis relates quantity of product to dynamics of herds and flocks (103, 106, 108, 109, 111, 116, 117, 124, 126, 128, 129, 135, 136, 141, 150, and 166). Detailed, elaborate supply models relate price to product by way of animal numbers and weights and herd composition. Supply specification in the GOL model requires a relatively simple relationship of quantity to price. What appears in the

GOL model is net effects limited to a reduced set of variables--expressed in terms of prices--simplified from arrays of detailed effects operating in many dimensions.

For each region included in the GOL model, a decision is made based on practical considerations, such as for which meats and other livestock commodities should supply relationships be established. If a livestock sector is included at all, at this stage, it will almost surely contain beef, since this commodity is the world regulator of the meat price surface. The close substitutes for beef are feed-intensive: pork and poultry. These three meats are important elements in the determination of feed quantities and prices. They cannot very well be omitted, just as mutton cannot be avoided in some regions. Dairy products constitute a separate, but highly interacting, subsector with strong implications for world prices and for consumption of grain and oilmeal.

Given the practical decision as to choice of commodities for each region, a further decision was made as to which direct- and cross-price effects to allow to enter the price-elasticity matrix and at what magnitudes. Previous work was studied and results interpreted in the light of assumptions incorporated into the work. The importance of such assumptions for projections to be generated by the GOL model helped determine relevance for inclusion in this work. Finally, a set of price elasticities was postulated and judged appropriate for the 15-year projection span involved in this model. Little previous work has been done to quantify the world in terms of only the regions stipulated here and with the specified limitations in commodity coverage. The result is that judgment entered into every price coefficient employed in the model. The elasticities are postulated and may be thought of as assumed. They are tentative and are subject to revision or change.

In many regions of the world and in much of the same period since World War II, output increases and price rises have occurred synchronously. This has made theoretical statistical separation of positive from negative price effects very difficult and results obtained questionable. In the case of meat and livestock products, the presence of multiyear cycles in production renders neat theoretical solutions even more difficult to obtain.

## Supply Structure by Region

This section presents the structure of world supply of livestock products by region, in the order of presentation in the previous section on demand. The findings included here have, in general, been interpreted in line with GOL model requirements. That is, supply structures, as found in the literature of agricultural economics or in manuscripts, have been simplified and some commodity fields ommitted. Livestock herds and flocks, for example, are not GOL-endogenous variables.

### United States

The World GOL Model is designed to work in conjunction with highly elaborate models of the United States. In the GOL model, however, the United States is represented by only a functional skeleton, which was given approximately the same commodity specification as the world. The resulting U.S. longrun and shortrun elasticities are shown here:

| Adjustment time and commodity | Supply-price elasticities | | | | | |
|---|---|---|---|---|---|---|
| | Beef | Pork | Poultry | Eggs | Corn | Feeders |
| Long run: | | | | | | |
| Beef | 0.25 | -- | -- | -- | -0.05 | -0.13 |
| Pork | -- | 0.73 | -- | -- | -.95 | -- |
| Poultry | -- | -- | 1.81 | -- | -.42 | -- |
| Eggs | -- | -- | -- | 0.15 | -.05 | -- |
| Short run: | | | | | | |
| Beef | .10 | -- | -- | -- | -- | -- |
| Pork | -- | .34 | -- | -- | -- | -- |
| Poultry | -- | -- | .14 | -- | -- | -- |
| Eggs | -- | -- | -- | -- | -- | -- |

-- = Not applicable.
Source: (145).

Table 25 shows elasticities calculated as an approximate interpretation of some of the more elaborate modeling of the United States. The commodity dimensions of this table are much reduced from the fuller U.S. model system; they are suggestive of the comparability of the approaches and indicative of the degrees of information lost through reducing the scale of the U.S. models. (For previous modeling of the U.S. livestock economy, see 105, 108, 109, 111, 115, 116, 117, 124, 137, and 166.)

Canada

Canada has been modeled after the United States. Suitable supply estimation is not easy to obtain, partly because the Canadians perceive the necessity of modeling their country in several regions each quite different from the others. Table 26 presents estimated direct-supply elasticities together with an indication of the variable pattern in which the elasticities were quantified. The algebraic sign associated with the other variables is also shown.

European Community

Supply-price analysis of European agriculture has not been adequately analyzed by econometric methods to date. This is due to several reasons. Importantly, persistently rising prices in Europe since World War II have rendered nearly all prices and most lines of physical agricultural commodity output highly correlated with time. The fact that European agriculture (crop and livestock) is the product of miltiproduct farms renders all outputs highly intercorrelated as well. Most meat, including beef and pork, is produced on grain-producing dairy farms where government policies concerning the prices of wheat and milk have exerted longrun, income-stabilizing effects. The full complexity of price effects on meat production has only been hinted in the GOL model as presently specified.

EC-6.--European economists have not developed aggregated analytical models of the European Community or its major parts. This author, however, has made some basic calculations of aggregated meat production of the original six members of the EC (145,

Table 25--United States: Supply-price elasticities and shifter 1/

| Commodity | Supply-price elasticity | | | | | | | | Shifter | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Fed beef | Nonfed beef | Pork | Broiler | Chicken | Turkey | Corn | Meal | Calf herd | Costs |
| Fed beef | 0.87 | -0.19 | -- | -- | -- | -- | -.34 | -.07 | 2.77 | -0.27 |
| Nonfed beef | -- | .25 | -- | -- | -- | -- | -.21 | -- | -- | -.04 |
| Pork | -- | -- | 0.60 | -- | -- | -- | -.34 | -.06 | -- | -.20 |
| Broilers | -- | -- | -- | 0.47 | -- | -- | -.24 | -.12 | -- | -.11 |
| Chicken 2/ | -- | -- | -- | -- | 0.18 | -- | -.04 | -.02 | -- | -.12 |
| Turkeys | -- | -- | -- | -- | -- | 1.07 | -.42 | -.14 | -- | -.51 |

| Commodity | Supply-price elasticity | | | | | | | | Shifter | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Nonfed beef | Veal | Milk | Eggs | Calves | Chicks | Corn | Meal | Dairy herd | Hay fed | Herd age | Cost | Time |
| Dairy beef | 0.55 | -- | -0.55 | -- | -- | -- | -- | -- | 5.10 | -- | -- | -- | -- |
| Veal | -- | 0.21 | -- | -- | -0.21 | -- | -0.64 | -0.14 | -- | -- | -- | -- | -- |
| Milk | -- | -- | .78 | -- | -- | -- | -- | -- | -- | 0.43 | 0.25 | -- | -- |
| Eggs | -- | -- | -- | 0.06 | -- | -0.08 | -.06 | -.02 | | -- | -- | 0.03 | 0.11 |

-- = Not applicable.
1/ Approximate interpretation of equations presented in the sources.
2/ Excluding broilers.

Sources: (127, 128, 129, and 169).

149, and appendix C). These are shown in table 27. Beef production is seen as positively influenced by a rise in either beef or milk price and negatively by a rise in grain price. Pork is Europe's most important meat and is shown as positively related to pork price and strongly negatively related to grain price. It should be noted that pork output tends to run countercyclically with beef.

Netherlands.—In table 28, the basic production relationship for both beef and milk is shown as the calf production function. It must be remembered that production of a live calf implies the beginning of lactation for the mother cow and the possible immediate production of veal. Saving the calf implies either beef production in 18 months to 2 years or production of additional milk in about 2 years. Pork is highly responsive positively to its own price and negatively to the price of feed. Poultry is also similarly responsive. The Dutch supply relationships are regression results from fitted functions.

Belgium.--A production relationship from a fitted regression equation showing beef output highly and positively responsive to beef and milk prices and negatively responsive to grain price is shown here. Inflation was accounted for by using variables from which the time trend had been removed.

| Commodity | Supply-price elasticity | | |
|---|---|---|---|
| | Beef | Grain | Milk |
| Beef | 1.50 | -0.23 | 0.40 |

Source: (1060).

The study also presents calculations of a beef demand-price elasticity of -1.0 and evidence that the cycle amplitudes of both beef prices and beef marketings are nearly the same.

United Kingdom.--The following tabulations show several tableaux of supply elasticities obtained from a variety of sources. The below elasticity coefficients presented by G.T. Jones at Oxford University contain the response to a change in a commodity's own price which is permitted to work itself out over a decade.

| Commodity | Supply elasticity with respect to direct price |
|---|---|
| Beef and veal | 1.05 |
| Cow beef | .82 |
| Mutton and Lamb | 2.04 |
| Pork | 9.60 |
| Bacon | 15.50 |
| Pigmeat | 4.00 |
| Poultry and game | 5.20 |
| Fish | 1.10 |
| Eggs | 2.20 |
| All milk | .73 |

Sources: (1033 and 1045).

Table 26--Canada: Supply-price elasticities and stock shifter 1/

| Commodity | Supply-price elasticity | | | | | Stock shifter | | | | Time |
|---|---|---|---|---|---|---|---|---|---|---|
| | Steers | Cows | Pork | Hog 2/ | Barley 2/ | Steers | Cows | Barley | Wheat | |
| Beef | 0.4 | -- | -- | -- | -- | + | -- | -- | -- | -- |
| | -- | 0.25 | -- | -- | -- | -- | + | -- | -- | -- |
| | -.4 | -- | -- | -- | -- | -- | -- | -- | -- | + |
| Pork | -- | -- | 0.10 | -- | -- | -- | -- | -- | -- | + |
| | + | -- | .15 | -- | -- | -- | -- | + | -- | -- |
| | + | -- | -- | 0.4 | -0.4 | -- | -- | -- | + | -- |
| | + | -- | -- | .4 | -.4 | -- | -- | -- | -- | + |

-- = Not applicable.

1/ Associated variables in calculated patterns are indicated by their signs (+ or -) from regression equations.

2/ Hogs, barley ratio. Source: (155).

Table 27--EC-6: Supply-price elasticity patterns from fitted equations, annual trends, and equation statistics 1/

| Commodity and Time lag 2/ | Supply-price elasticity | | | | | Annual trend | Equation statistic | | |
|---|---|---|---|---|---|---|---|---|---|
| | Meat | Beef | Pork | Milk | Grain | | $R^2$ | SE | DW |
| | | | | | | Percent | | | |
| Meat (1 year) | 1.20 | -- | -- | -- | -- | -- | 0.85 | 0.63 | 1.2 |
| | .14 | -- | -- | -- | -0.52 | -- | .86 | .60 | 1.5 |
| | .82 | -- | -- | 0.63 | -.70 | -- | .92 | .46 | 1.6 |
| | .25 | -- | -- | -- | -.29 | 1.88 | .99 | .19 | 1.9 |
| Meat (2 years) | 1.16 | -- | -- | -- | -- | -- | .94 | .40 | 2.2 |
| | .69 | -- | -- | .44 | -- | -- | .96 | .31 | 1.6 |
| | .70 | -- | -- | .47 | -.11 | -- | .96 | .32 | 1.7 |
| Beef (2 years) | -- | 0.63 | -- | -- | -.25 | -- | .83 | .17 | 1.0 |
| | -- | .60 | -- | .65 | -.29 | -- | .82 | .18 | 1.0 |
| | -- | .60 | -- | .05 | -- | -- | .83 | .17 | 1.0 |
| Pork (1 year) | -- | -- | 0.27 | -- | -.37 | 1.83 | .97 | .10 | 2.5 |
| | -- | .31 | .69 | -- | -.40 | -- | .86 | .23 | 1.8 |
| | -- | -.10 | .30 | -- | -.34 | 2.05 | .97 | .10 | 2.4 |

-- = Not applicable.

1/ Using ordinary least squares, annual aggregated data for the EC-6, deflated prices for 1950 to 1965. Calculations are further to those presented by D.W. Regier (145 and 149).

2/ The time lag is the number of years previously that the prices in the supply-price elasticity columns occurred as compared with observed quantities of the indicated commodity.

Source: Appendix C.

Table 28--Netherlands: Supply-price elasticities and shifter

| Commodity | Supply-price elasticity | | | | | | Shifter | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Beef | Pork | Poultry | Eggs | Milk | Feed | Effic-iency | Wages | Profit-ability | Time |
| Calves 1/ | -0.25 | -- | -- | -- | 0.43 | -0.18 | 0.40 | -- | -- | -- |
| Pork | -- | 2.4 | -- | -0.2 | -- | -2.10 | .45 | -0.02 | -- | -- |
| Poultry | -- | -- | 0.79 | -- | -- | -.79 | -- | -- | 0.36 | 0.11 |

-- = Not applicable.
1/ Basic production relationship for milk, beef, and veal, interpreted with appropriate lags.

Sources: Approximate interpretation, by separate calculation, of basic equations included in Netherlands, (416 and 1052).

Similarly the Ferris and Josling study shows the cumulation of price response effects over a span of 5 years (table 29). The McFarquhar study below shows a high order of price response measured econometrically in the form of calf production related to beef and milk prices.

| Commodity | Supply-price elasticity | | |
|---|---|---|---|
| | Beef price | | Producer milk price |
| | Guaranteed | Market | |
| Male calves | 4.2 | 2.7 | -- |
| Female calves | -- | .7 | 3.8 |

-- = Not applicable. Source: (1045).

Denmark.--The Ferris and Josling study also contained a tabulation of cumulated price responses to various price changes in the feed-livestock sector of Denmark (table 30). Some of the responses appear to be perverse and in the wrong direction, but this is difficult to judge without more detailed knowledge of the entire model.

## Other Western Europe

Sweden's agricultural production economists have provided usable estimates of production response to price incentives in the meat and livestock sector. Gulbrandsen and Stojkovic have presented valuable regression results for Swedish beef and pork production. An interpretation of their equations in (1026) is as follows:

| Commodity | Supply-price elasticity | | | Shifter | | |
|---|---|---|---|---|---|---|
| | Beef | Pork | Feed grains | Grain yield | Pig herd | Wages |
| Beef | 1.26 | -- | -1.26 | 0.50 | -- | -- |
| Pork | -- | .11 | -.11 | -- | 0.59 | -0.59 |

-- = Not applicable.

Regression results obtained by Winfridsson (table 31) broadly confirm these, as well as indicating the variability of numerical quantification in this area. Results are lacking for other countries of Western Europe.

## Oceania

Powell, Gruen, and their associates in Australia have formulated useful tableaux showing cross-price supply elasticites and direct-price responses for the very basic commodity categories of the feed-livestock complex, as shown in tables 32 and 33. The tables show both shortrun and longrun price effects. The tables include variables

Table 29--United Kingdom: Supply response

| Effect of a 1-percent price increase on production 1/ | | | | | |
|---|---|---|---|---|---|
| Commodity being priced | Product | Years after price change | | | |
| | | 1 | 2 | 3 | 5 |
| | | Percent | | | |
| Milk | Milk | 0.34 | 0.53 | 0.68 | 0.82 |
| Barley | Milk | -.06 | -.10 | -.14 | -.16 |
| Cattle | Beef | -.02 | .10 | .25 | -.07 |
| Pigs | Pork | .97 | 1.51 | 2.00 | 2.22 |
| Broilers | Broilers | .45 | .87 | 1.31 | 2.05 |
| Turkeys | Turkeys | .50 | .79 | .98 | 1.17 |
| Eggs | Eggs | .35 | .60 | .80 | 1.06 |
| Barley | Feed grain | .25 | .51 | .74 | 1.09 |
| Wheat | Wheat | .19 | .24 | .25 | .27 |
| Barley and wheat | Cereals | .28 | .56 | .81 | 1.21 |
| Barley, wheat, and maize | Concentrate utilization | -.21 | -.33 | -.46 | -.55 |

1/ Price changes include effects of taxes and subsidies. Production response is free from restrictions (including area). Source: (302).

Table 30--Denmark: Supply response

| Effect of a 1-percent price increase on production 1/ | | | | | |
|---|---|---|---|---|---|
| Commodity being priced | Product | Years after price change | | | |
| | | 1 | 2 | 3 | 5 |
| | | Percent | | | |
| Milk | Milk | 0.19 | 0.35 | 0.46 | 0.61 |
| Dairy feed | Milk | -.04 | -.07 | -.10 | -.13 |
| Heifer beef | Heifer and steer beef | .14 | -.07 | -.27 | -.60 |
| Pigmeat | Pigmeat | 0 | 1.20 | 2.32 | 4.07 |
| Broilers | Poultry meat | 0 | 0 | 0 | 0 |
| Eggs | Eggs | .23 | .44 | .64 | 1.04 |
| Barley | Cereals | .08 | .16 | .25 | .43 |
| Barley | Concentrate utilization | -.01 | -.29 | -.59 | -1.07 |

1/ Price changes include effects of taxes and subsidies; production response is free of restrictions. Neutralizing the effects of cull cow prices (tied to heifer beef in the model) results in a supply elasticity for heifer and steer beef of +0.20 by the 5th year. Source: (302).

Table 31--Sweden: Supply-price elasticities from regression and supply shifter 1/

| Commodity | Supply-price elasticity | | | | | Supply shifter | | Constant | $R^2$ DW |
|---|---|---|---|---|---|---|---|---|---|
| | Beef | Pork | Milk | Eggs | Feed | Effi- ciency | Resource | | |
| Beef | 1.04 | -- | -- | -- | -1.04 | 1.09 | 0.61 | -0.85 | 0.94<br>1.72 |
| Pork | -- | 0.31 | -- | -- | -.31 | .28 | -- | 3.81 | .84<br>1.72 |
| Milk | -- | -- | 0.09 | -- | -.09 | .38 | .60 | -- | .96<br>.94 |
| Eggs | -- | -- | - | 0.23 | -.23 | .41 | -- | 4.24 | .89<br>2.63 |
| | Wheat | Feed grain | Potatoes, lagged | | | | | | |
| | | | 1 year | 2 years | 3 years | | | | |
| Wheat | 0.91 | -- | -- | -- | -- | .92 | -- | -3.86 | .60<br>1.44 |
| Feed grain | -- | 0.18 | -- | -- | -- | .95 | .59 | -3.69 | .98<br>1.76 |
| Potatoes | -- | -- | 0.25 | 0.29 | 0.26 | .64 | -1.07 | -4.58 | .94<br>2.54 |

1/ Logarithmic form, deflated prices, analysis period 1951-67.

Sources: (1073 and 1074).

Table 32--Australia: Shortrun supply-price elasticities 1/

| Commodity | Beef and veal | Dairy | Lamb | Wool | Wheat | Coarse grains |
|---|---|---|---|---|---|---|
| Beef and veal | 0.16 | -0.16 | -- | -- | -- | -- |
| Dairy | -.13 | .20 | -0.06 | -- | -- | -- |
| Lamb | -- | -.20 | .32 | -0.12 | -- | -- |
| Wool | -- | -- | -.18 | .07 | -0.05 | -- |
| Wheat | -- | -- | -- | -.11 | .18 | -0.07 |
| Coarse grains | -- | -- | -- | -- | -.22 | .22 |

-- = Not applicable.
1/ The shortrun refers to year-to-year development.

Sources: (1057 and 122).

Table 33--Australia: Direct supply-price elasticities 1/

| Commodity | Shortrun, 1 year | Medium run, 5 years | Longrun, infinite |
|---|---|---|---|
| Beef and veal | 0.16 | NE | NE |
| Dairy | .20 | 0.43 | 0.46 |
| Wool | .05 | .25 | 3.59 |
| Lamb | .21 | .94 | 3.20 |
| Wheat | .18 | .82 | 3.82 |
| Coarse grains | .21 | .81 | 1.54 |

NE = Not estimated.
1/ Nerlovian estimates.

Source: (411).

not admitted in the GOL model and omit others that are in the model. Work remains for the GOL model in adequately treating mutton and wool. The interaction between dairy and beef production is also highlighted.

New Zealand beef and dairy supply responses are suggested in the figures presented here:

| Commodity | Direct-price elasticity | |
|---|---|---|
| | Shortrun | Longrun |
| Beef cattle | 0.09 | 0.64 |
| Dairy cattle | .18 | .42 |

Source: (103).

## Argentina

Table 34 contains a summary of Argentine supply-price elasticities drawn from a livestock study by the Instituto Nacional de Tecnologia Agropecuaria (INTA) (402), also quoted in Hutchison, Urban, and Dunmore (131). The quoted study brings together the work of a number of students of the problem of supply response in Argentina. The analytical work of Kohout is held to be of especially distinguished quality. His results, by and large, are used as guidelines in the GOL model. It can be observed that the response period is critical. Elasticity measurements range from strong negative (with a short timelag) to stronger positive (with a 3-year lag). These studies are noteable for having been conducted in a context of high price inflation. They will serve as a strong basis for further analysis.

## Brazil

Work by the Getulio Vargas Foundation is summarized in table 35. Analysis has been under way in Brazil for several decades into quantification of important production functions underlying Brazil's agriculture. Table 35 provides insight into the technical foundation of the Brazilian agricultural sector, of its national accounts, and of certain production responses that are in operation. Immediately usable production elasticities with respect to price change are not apparent, but the relative importance of meat production is suggested.

## Longrun Supply Growth

Plausible estimates of livestock supply elasticites are usually estimated along with the effect of weather, physical inputs, technological growth, cycles, and other factors. Considerations of theoretical symmetry and homogeneity apply to production as well as to consumption. At this stage of modeling the livestock sector, neutrality or central values have been assumed for commodity cycles, weather, and separate physical inputs. Additional factors in operation, after allowance for price effects, are treated as combined into technological effects and related to time. Adjustment for such effects may be once-and-for-all, constant increment, or compound growth. Exgenous growth terms used in livestock supply and feed demand are shown in table 36.

Table 34--Argentina: Beef supply-price elasticities, by source

| Source | Supply-price elasticity | | Characteristics |
|---|---|---|---|
| | Shortrun | Longrun | |
| INTA | -- | 0.23 | Price is 3-year moving average centered on t-3, 1956-65 |
| | -- | .39 | Price is t-3 |
| Reca | -- | -.36 | 1923-47 |
| | -- | -.21 | 1948-65 |
| Otrera | -2.48 | -2.66 | 1945-64 |
| Nores | -.003 | -.314 | 1935-66 |
| Kohout | -.61 | -- | Price is t-1, 1935-67 |
| | -- | .69 | t-2 |
| | -- | .98 | t-3 |
| | -- | .68 | t-4 |
| | -- | .05 | t-5 |

-- = Not applicable. Sources: (402, 1059, 1054, 1053, 1041, and 131).

Table 35--Brazil: Technical coefficients and agricultural output elasticities with respect to input

| Input | Technical coefficient | | | Output elasticity | | |
|---|---|---|---|---|---|---|
| | Total | Crop | Livestock | Total | Crop | Livestock |
| Total land area | 0.007 | -- | -- | 0.162 | -- | -- |
| Crop area | -- | 0.002 | -- | -- | 0.477 | -- |
| Pasture area | -- | -- | 0.003 | -- | -- | -0.067 |
| Seeds and seedlings | .020 | .025 | -- | .119 | .107 | -- |
| Livestock feed | .052 | -- | .076 | .087 | -- | .150 |
| Fertilizers | .003 | .004 | -- | .043 | .057 | -- |
| Pesticides | .002 | .002 | -- | .053 | .058 | -- |
| Vaccines and medicines | .001 | -- | .001 | .037 | -- | .070 |
| Labor | .459 | .525 | .395 | .160 | .117 | .184 |
| Value of land, plantings | 4.129 | 4.133 | 4.035 | .107 | .064 | .257 |
| Buildings, machines, equipment | 1.403 | 1.369 | 1.470 | .102 | .129 | .112 |
| Cows for breeding | .040 | -- | .153 | .005 | -- | -.015 |
| Sows for breeding | .003 | -- | .002 | .001 | -- | .014 |
| Livestock herd 1/ | .196 | -- | .421 | .031 | -- | .091 |

-- = Not applicable. 1/ For other than breeding or work. Sources: (408 and 409).

Table 36--World GOL Model: Exogenous growth coefficients for feed demand and livestock supply 1/

| Commodity | Type of growth 2/ | United States | Canada | EC-3 | EC-6 | Other Western Europe | Japan | Australia | Middle America | Brazil | Argentina |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Percent per annum | | | | | | | | | |
| Feed demand: | | | | | | | | | | | |
| Grain | T | 0.3 | 0.2 | 0.2 | 0.5 | -- | 0.5 | 0.2 | -- | -- | -- |
| Oilmeal | T | 1.0 | .5 | -- | -- | -- | 1.0 | 2.0 | -- | -- | -- |
| | P | -- | -- | .5 | .4 | -- | -- | -- | -- | -- | -- |
| Livestock supply: | | | | | | | | | | | |
| Beef | P | 1.6 | 3.5 | 2.5 | 2.0 | 3.1 | 2.0 | 3.0 | 3.8 | 3.25 | 1.5 |
| Pork | T | -- | -- | -- | -- | -- | -- | .5 | -- | -- | -- |
| | P | .5 | 1.9 | 2.9 | 2.4 | 2.0 | 2.0 | -- | 3.8 | 3.5 | 2.5 |
| Poultry | P | 2.5 | 5.6 | 2.5 | 4.4 | 6.0 | 5.0 | -- | -- | -- | -- |
| Mutton | P | -- | -- | -- | -- | .6 | -- | 2.2 | -- | -- | .2 |
| Milk | P | -- | 1.9 | .73 | .3 | 1.5 | 5.0 | 1.0 | -- | -- | -- |
| Cheese | P | -- | -- | -- | 1.0 | -- | -- | -- | -- | -- | -- |

-- = Not applicable.

1/ Residual incremental and compound growth terms after allowance for the effects of elasticities and other parameters in the model specification, both endogenous and exogenous.

2/ T is an incremental trend expressed as a percent of base; P is a compound growth rate.

## World GOL Model Supply Elasticities

Supply elasticities of meat (table 37) and dairy products (table 38) were synthesized from an evaluation of all material previously presented. These elements were adjusted to account for variations in the commodity specification adopted for the World GOL Model and of the individual investigations utilized. Adjustment also was attempted, where possible, for variation in the time frames over which elasticities were calculated or intended to be utilized. The supply response estimates for a number of regions are weak or inappropriate for the purposes of the GOL model. In such cases, the global uniformities of the Main Sequence on world feed allocation and meat demand were born in mind, and the regions concerned were modeled in relation to regions borne with better known responses. The parameter specification is tentative and subject to reevaluation after any additional research might be completed.

## DERIVED DEMAND STRUCTURE FOR LIVESTOCK FEED

The link between the crop and livestock sectors of the World GOL Model is importantly a physical one. The quantity of a commodity demanded as feed is a weighted sum of the livestock commodities produced in a region, the weights are the respective quantities of the feed used in producing a given livestock product, and the final sum is then adjusted by price considerations. The feed commodities central to the GOL model are grain and oilmeal. First, calculations of grain used as feed are made as a broad category. Second, grain is apportioned into feed demand separately for wheat, coarse grain, and rice. The equation patterns for derived demand for livestock feed have the following general form, as illustrated by grain:

| | | |
|---|---|---|
| Feed grain demand = | F (Production of:<br>Beef<br>Pork<br>Poultry<br>Mutton<br>Milk<br>Price of:<br>Beef<br>Pork<br>Corn<br>Oilmeal) | + G (Change in:<br>Taste<br>Policy<br>Technology<br>--and to account for livestock not treated endogenously--<br>Income per capita<br>Population<br>Productivity) |
| Feed wheat demand = | F (Feed grain demand<br>Price of:<br>Wheat<br>Corn | + G (Change in:<br>Policy<br>Technology) |
| Feed corn demand = | Feed grain demand | - Feed wheat demand |

where F is a matrix of linear functions of endogenous variables and G is a set of exogenous independently projected factors. Like demand functions for livestock products and for grain used as food, demand for feed is related to a matrix of direct- and cross-price elasticities. Additionally, it is related to the physical production of the endogenous livestock products by a set of input-output coefficients expressing the tons of grain or meal used to produce a ton of livestock product. The G-functions include factors such as technological change or policy considerations which affect the use of grain or meal as livestock feed. They also include factors such as per capita income and population to account for those parts of the livestock sector which are not as yet specified by appropriate F-functions.

Table 37--World GOL Model: Supply elasticities for meat, by region or country

| Item | Supply elasticity with respect to price of-- | | | | | | |
|---|---|---|---|---|---|---|---|
| | Beef | Pork | Poultry | Mutton | Milk | Corn | Oilcake |
| United States: | | | | | | | |
| Beef | 0.30 | -- | -- | -- | -- | -0.20 | -0.05 |
| Pork | -- | 0.60 | -- | -- | -- | -.40 | -.10 |
| Poultry | -- | -- | 0.90 | -- | -- | -.60 | -.20 |
| Canada: | | | | | | | |
| Beef | .40 | -.10 | -- | -- | -- | -.20 | -.05 |
| Pork | -.20 | .60 | -.20 | -- | -- | -.40 | -.10 |
| Poultry | -.10 | -.20 | .70 | -- | -- | -.40 | -.20 |
| EC-6: | | | | | | | |
| Beef | .40 | -.15 | -- | -- | 0.15 | -.20 | -.10 |
| Pork | -.30 | .70 | -.30 | -- | -- | -.40 | -.20 |
| Poultry | -.20 | -.20 | .70 | -- | -- | -.40 | -.30 |
| Mutton | -.15 | -- | -- | 0.30 | .15 | -- | -- |
| EC-3: | | | | | | | |
| Beef | .40 | -.15 | -- | -- | .15 | -.20 | -.10 |
| Pork | -.15 | .70 | -.15 | -- | -- | -.40 | -.20 |
| Poultry | -.20 | .20 | .70 | -- | -- | -.40 | -.30 |
| Mutton | -.15 | -- | -- | .30 | .15 | -.15 | -- |
| Other Western Europe: | | | | | | | |
| Beef | .40 | -.15 | -- | -- | .15 | -.20 | -.10 |
| Pork | -.20 | .50 | -.20 | -- | -- | -.30 | -.15 |
| Poultry | -.20 | -.20 | .60 | -- | -- | -.30 | -.25 |
| Mutton | -.15 | -- | -- | .30 | .15 | .15 | -- |
| Japan: | | | | | | | |
| Beef | .50 | -.10 | -.10 | .20 | -- | -.30 | -- |
| Pork | -- | .70 | -.20 | -.15 | -- | -.40 | -.20 |
| Poultry | -- | -.20 | .70 | -- | -- | -.40 | -.30 |
| Oceania: | | | | | | | |
| Beef | .40 | -- | -- | -.10 | -- | -- | -- |
| Pork | -.10 | .30 | -- | -- | -- | .20 | -- |
| Poultry | -.10 | -- | .30 | -- | -- | -- | -- |
| Mutton | .20 | -- | -- | .20 | -- | -- | -- |
| Mexico and Central America: | | | | | | | |
| Beef | .40 | -.10 | -- | -- | -- | -- | -- |
| Pork | -.10 | .30 | -- | -- | -- | -.40 | -- |

Continued--

Table 37--World GOL Model: Supply elasticites for meat, by region or country--Continued

| Item | Supply elasticity with respect to price of-- | | | | | | |
|---|---|---|---|---|---|---|---|
| | Beef | Pork | Poultry | Mutton | Milk | Corn | Oilcake |
| Argentina: | | | | | | | |
| Beef | .50 | -- | -- | -- | -- | -- | -- |
| Pork | -.10 | .30 | -- | -- | -- | -.2 | -- |
| Mutton | -- | -- | -- | .20 | -- | -- | -- |
| Brazil: | | | | | | | |
| Beef | .50 | -- | -- | -- | -- | -- | -- |
| Pork | -.10 | .40 | -- | -- | -- | -.30 | -.15 |

-- = Not applicable.

Sources: United States--See text, table 25 and sources cited, and (132, 110, and 1027);
Canada--see table 26 and source cited;
EC-6--see table 27, apendix C, and (145 and 149), consult text table 28 and sources cited; and compare sources listed for the EC-3 and Other Western Europe;
EC-3--for the United Kingdom, see the text and table 29 and sources cited, for Denmark see table 30 and sources, and compare sources listed for the EC-6 and Other Western Europe;
Other Western Europe--see the text, table 31, and sources cited, and consult references to the EC-6 and EC-3;
Oceania--for Australia, see tables 32 and 33 and sources cited, and for New Zealand, see the text and sources cited;
Argentina--see table 34 and the sources cited;
Brazil--see table 35 and sources cited.

Table 38--World GOL Model: Supply elasticities for dairy products, by region

| Item | Supply elasticity with respect to price of-- | | | | | Supply elasticity of joint output with beef |
|---|---|---|---|---|---|---|
| | Milk | Butter | Cheese | Corn | Oilcake | |
| United States: | | | | | | |
| Milk, total | 0.40 | -0.10 | -- | -0.30 | -0.20 | -- |
| Cheese | -- | -.60 | 0.60 | -- | -- | -- |
| Canada: | | | | | | |
| Milk, total | .30 | -- | -- | -.40 | -.20 | -- |
| Cheese | -- | -.60 | .60 | -- | -- | -- |
| EC-6: | | | | | | |
| Milk, total | .35 | -- | -- | -.50 | -.30 | 0.5 |
| EC-3: | | | | | | |
| Milk, total | .35 | -- | -- | -.20 | -.10 | -- |
| Other Western Europe: | | | | | | |
| Milk, total | .30 | -.35 | -- | -- | -.10 | -- |
| Cheese | -- | -- | .50 | -- | -- | -- |
| Japan: | | | | | | |
| Milk, total | .80 | -- | -- | -.25 | -.30 | -- |
| Oceania: | | | | | | |
| Milk, total | .40 | -- | -- | -.20 | -- | -- |
| Cheese | -- | -1.0 | 1.0 | -- | -- | -- |

-- = Not applicable.

Source: See table 37 and sources cited.

## The Feed-Livestock Balance

In the base from which the World GOL Model projections are made (1970, or a span of years centered on 1970), the quantities of livestock commodities produced are balanced with the quantities of feed imputed to each kind of animal or product. This budgeting is based on feed conversion rates characteristic of different livestock products, different farming systems, and prevailing practices in each of the regions of the World GOL Model. Tables 39, 40, and 41 are examples of the result of the budgeting process carried out for each GOL region. Identified in the tables are the quantities of livestock products, quantities of grain consumed as feed for each product and in total, and quantities of oilmeal consumed as feed for each livestock product and in total for the region. Also explicitly identified are the use rates--or input-output ratios--for both grain and oilmeal, expressing the tons of grain (or oilmeal) used in producing a ton of livestock product. Such balances for each region are used to obtain input-output ratios incorporated into the feed demand equations. The use rates are adjusted to account for the grain or meal reported as livestock feed in each region.

## Input-Output Coefficients

The heart of the system comprising the interface between crop and livestock sectors of the World GOL Model is a comprehensive set of input-output coefficients relating, in the 1970 base, production of meat and other individual livestock products to the quantities of grain and oilmeal used in their production. To establish these coefficients, research reports were studied and screened for estimates of the coefficients which might be useful for modeling the region in which the research had been carried out. The coefficients decided upon were expressed in the dimensions of the GOL model in terms of the implied quantity of feed used per unit of product. Grains and oilmeals were then budgeted, in the 1970 base, to account for the entirety of grains and meals and of livestock products. The observed discrepancies led, for a particular region, either (1) to a second round of estimation of coefficients, or (2) to an estimation procedure which respected the coefficients but treated the discrepancy term explicitly as a function of time in the projections. Tables 42, 43, and 44 are work sheets based on this method.

Observed input-output coefficients for feed into livestock commodities are behavioral relationships depending on (1) biological considerations, (2) local climate and plant ecologies, and (3) affluence of the agriculturalist in his environment in making decisions bearing on the sharing of available crops by the family, the market, or animals in the form of feed. The practices in U.S. agriculture are well known and clearly documented, but they stand at an extreme of behavior with respect to affluence or per capita income of the world. Other developed countries less affluent than the United States are less elaborate in their documentation of local agricultural practices (or less forthcoming in publication of these practices) and typically use lesser quantities of grain in feeding livestock. The appreciable variation in agricultural practices (e.g., throughout Europe) and the less than comprehensive publication programs by some otherwise advanced countries make documentation by region difficult and, thus, data uneven. For the less developed countries, lacking resources for adequate attention even to basic concerns of human health and nutrition, documentation of livestock nutrition and husbandry practices tends to be quite poor. Thus, the basis is lacking for elaborate procedures of statistical estimation.

As countries form a progression when classified on the scale of per capita income, reliability of livestock feeding data form a similar progression when compared on the income scale. However, the allocation of grain to livestock at the expense of food also tends to form a progression on the same scale (according to the scattered information available). Therefore, a basis exists for arriving at judgments

Table 39--EC-6: Livestock production, grain utilization rates, and grain used as feed, 1962 1/

| Product | Livestock production | Grain utilization rate | Grain used as feed |
|---|---|---|---|
| | Million metric tons | Rate | Million metric tons |
| Total meat (with grain inputs allocated) | 10.377 | (2.077) | 21.549 |
| Major meats: | 9.800 | (2.184) | 21.404 |
| Beef and veal: | 4.210 | (.743) | 3.127 |
| Beef | 3.467 | .902 | 3.127 |
| Veal | .743 | 0 | 0 |
| Pork | 4.613 | 3.410 | 15.730 |
| Poultry | .977 | 2.607 | 2.547 |
| Minor meats | .577 | .251 | .145 |
| Other products: | | | |
| Milk | 65.407 | .111 | 7.260 |
| Eggs | 1.957 | 3.109 | 6.084 |
| Total meat and livestock products | -- | -- | 34.893 |
| Total meat (with grain inputs unallocated) | 10.377 | (3.362) | 34.893 |

-- = Not applicable.

1/ Grain used as feed is calculated by multiplying the detail of livestock production by grain utilization rates and summing to obtain the total of grain used as feed to check with reported data. Average utilization rates (shown in parentheses) are obtained by dividing subtotals and totals of calculated grain used as feed by the corresponding subtotal or total of livestock production.

Source: Adapted from (145).

Table 40--EC: Livestock production and use of grain and meal as feed, 1970

| Product | Livestock production | Grain used as feed | | Oilmeal used as feed | |
|---|---|---|---|---|---|
| | Million metric tons 1/ | Rate 2/ | Million metric tons 3/ | Rate 2/ | Million metric tons 3/ |
| EC-6: | | | | | |
| Meat: 4/ | 13.000 | (2.278) | 29.616 | (0.490) | 6.364 |
| Beef and veal | 4.416 | 1.300 | 5.741 | .160 | .707 |
| Pork | 5.061 | 3.600 | 18.220 | .670 | 3.391 |
| Poultry | 1.920 | 2.700 | 5.184 | 1.180 | 2.266 |
| Mutton | .195 | .250 | .049 | -- | -- |
| Minor meat | 1.408 | .300 | .422 | -- | -- |
| Other products: | | | | | |
| Milk | 71.448 | .130 | 9.288 | .034 | 2.429 |
| Eggs | 2.492 | 3.100 | 7.725 | .710 | 1.769 |
| Meat 5/ | 13.000 | (3.587) | 46.629 | .812 | 10.562 |
| EC-3: | | | | | |
| Meat: 4/ | 4.500 | (2.844) | 12.797 | (.420) | 1.891 |
| Beef and veal | 1.334 | 2.270 | 3.028 | .120 | .160 |
| Pork | 1.838 | 4.220 | 7.756 | .550 | 1.011 |
| Poultry | .686 | 2.700 | 1.852 | 1.050 | .720 |
| Mutton | .267 | .250 | .067 | -- | -- |
| Minor meat | .375 | .250 | .094 | -- | -- |
| Other products: | | | | | |
| Milk | 20.778 | .210 | 4.363 | .025 | .519 |
| Eggs | 1.016 | 3.100 | 3.150 | .600 | .610 |
| Meat 5/ | 4.500 | (4.513) | 20.310 | .671 | 3.020 |
| EC-9: | | | | | |
| Meat | 17.500 | (2.424) | 42.413 | (.472) | 8.255 |
| Milk | 92.226 | (0.148) | 13.651 | (.032) | 2.948 |
| Eggs | 3.508 | (3.100) | 10.875 | (.678) | 2.379 |
| Feed 6/ | -- | -- | 66.939 | -- | 13.582 |
| Reported feed 7/ | -- | -- | 66.911 | -- | 13.574 |

-- = Not applicable.

1/ FAS supply and distribution figures (220 and 221) supplemented by FAO (702, 702, 703, and 704) and OECD (901, 902, and 903).

2/ Kilograms of feed per kilogram of livestock product. Use rates are obtained by budgeting with a priori knowledge from table 39 and (145, p. 6, 804, pp. 118-9, 806, 807, 808, 810, 122, 506, 507, 508, 509, 510, 501, 502, 503, 504, 505, 1056, 1057, 1072, 1047, 1048, 1049, 1050, and 1051).

3/ Detail is multiplication of livestock product detail by use rates. Average use rates for aggregated categories are shown in parentheses.

4/ Total meat with feed inputs allocated to all livestock products.

5/ Total meat with feed inputs unallocated.

6/ Sum of the calculated detail of allocated feed.

7/ Grain and oilmeal used as feed, as reported by FAS.

Table 41--United States: Livestock production and use of grain and meal as feed, 1970

| Product | Livestock production | Grain used as feed | | Oilmeal used as feed | |
|---|---|---|---|---|---|
| | Million metric tons 1/ | Rate 2/ | Million metric tons 3/ | Rate 2/ | Million metric tons 3/ |
| Meat (with feed allocated) | 22.120 | (4.8600) | 107.504 | (.4931) | 10.908 |
| Beef | 10.063 | 4.1807 | 42.070 | .2842 | 2.860 |
| Pork | 6.227 | 6.4313 | 40.048 | .4060 | 2.528 |
| Poultry | 4.634 | 2.7648 | 12.812 | .7883 | 3.653 |
| Mutton | .250 | 1.8560 | .464 | .2800 | .070 |
| Other | .946 | 12.8013 | 12.110 | 1.9000 | 1.797 |
| Other: | | | | | |
| Milk | 53.162 | .3272 | 17.396 | .03007 | 1.599 |
| Eggs | 4.077 | 2.9119 | 11.872 | .4236 | 1.727 |
| Meat (with feed unallocated) | 22.120 | (6.1832) | 136.772 | (.64349) | 14.234 |
| Feed: | | | | | |
| Estimated 4/ | -- | -- | 136.772 | -- | 14.234 |
| Actual 5/ | -- | -- | 136.343 | -- | 14.234 |

-- = Not applicable.

1/ ESCS supply and distribution figures: meat (214, poultry and eggs (215), milk (208 and 218 various issues).

2/ Kilograms of feed per kilogram of livestock product. Use rates are obtained by dividing feed detail by livestock product detail.

3/ Feed detail is from (201, 202, 209, and 217).

4/ Sum of calculated feed detail, as above.

5/ Grain and oilmeal use as feed, as reported by ESCS.

The analytical basis of this method was laid by USDA's Hodges (222) and Jennings (223), followed by Allen (201 and 202).

Table 42--Developed countries: Grain utilization rates for livestock production, 1962

(Kilograms of grain fed per kilogram of product)

| Region or country | Pork | Poultry | Beef and veal | Milk | Eggs |
|---|---|---|---|---|---|
| | | | Rate | | |
| United States | 8.30 | 4.40 | 3.0 | 0.30 | 3.90 |
| Canada | 7.80 | 2.40 | 5.0 | .30 | 4.90 |
| Japan | 6.30 | 1.80 | 1.2 | .30 | 2.70 |
| OECD-Europe | 3.80 | 3.70 | 1.7 | .80 | 3.50 |
| European Community: | 3.40 | 4.00 | 1.2 | .05 | 4.00 |
| Belgium-Luxembourg | 3.07 | 3.00 | 1.6 | .06 | 2.40 |
| Netherlands | 2.98 | 3.50 | 1.8 | .07 | 2.84 |
| France | 3.65 | 4.05 | 1.2 | .04 | 3.20 |
| Germany | 2.74 | 4.50 | .9 | .05 | 3.75 |
| Italy | 7.30 | 4.20 | 1.6 | .10 | 5.70 |
| North Western Europe: | 4.40 | 3.20 | 1.8 | .11 | 2.90 |
| Austria | 4.00 | 3.20 | 1.0 | .07 | 3.00 |
| Denmark | 4.20 | 3.10 | 2.1 | .10 | 3.90 |
| Finland | 4.90 | -- | 3.6 | .10 | 3.20 |
| Ireland | 1.60 | -- | 1.5 | .10 | 2.00 |
| Norway | 4.00 | 3.00 | 2.5 | .10 | 2.00 |
| Sweden | 5.00 | 4.10 | 2.6 | .10 | 3.70 |
| Switzerland | 2.70 | 3.80 | .8 | -- | 3.50 |
| United Kingdom | 5.10 | -- | 1.7 | .10 | 3.10 |
| Other Western Europe: | 5.00 | 3.30 | 4.1 | .25 | 3.10 |
| Greece | 4.00 | 3.50 | 1.5 | .10 | 3.00 |
| Portugal | 3.00 | .80 | 1.4 | .20 | .90 |
| Spain | 4.50 | 3.50 | 3.0 | .20 | 3.50 |
| Turkey | -- | 1.00 | 6.0 | .30 | 1.00 |
| Yugoslavia | 6.50 | 4.00 | 5.5 | .30 | 5.50 |
| Oceania: | 2.10 | 2.10 | .3 | .02 | 2.70 |
| Australia | 2.50 | 1.80 | .5 | .10 | 2.70 |
| New Zealand | 1.50 | 2.90 | .1 | .10 | 2.70 |
| OECD-Oceania | 5.80 | 4.00 | 2.4 | .14 | 3.60 |

-- = Not applicable.

Source: (804).

Table 43--Developed countries: Grain utilization rates for livestock production, 1975

(Kilograms of grain fed per kilogram of product)

| Region or country | Pork | Poultry | Beef and veal | Milk | Eggs |
|---|---|---|---|---|---|
| | | | Rate | | |
| United States | 8.30 | 4.20 | 3.6 | 0.30 | 4.00 |
| Canada | 7.80 | 2.20 | 4.0 | .30 | 4.40 |
| Japan | 6.60 | 2.30 | 1.2 | .20 | 2.30 |
| OECD-Europe | 3.50 | 3.00 | 2.3 | .11 | 3.10 |
| European Community: | 3.00 | 3.10 | 1.9 | .07 | 3.10 |
| Belgium-Luxembourg | 3.00 | 2.87 | 1.8 | .06 | 2.36 |
| Netherlands | 2.63 | 2.75 | 2.2 | .09 | 2.60 |
| France | 3.00 | 3.00 | 2.3 | .07 | 2.50 |
| Germany | 2.45 | 2.98 | 1.2 | .06 | 2.73 |
| Italy | 6.20 | 3.60 | 1.6 | .10 | 4.80 |
| North Western Europe: | 4.00 | 2.80 | 2.5 | .15 | 2.80 |
| Austria | 3.80 | 3.00 | 1.5 | .10 | 3.20 |
| Denmark | 4.40 | 2.50 | 2.4 | .10 | 3.50 |
| Finland | 5.00 | 2.60 | 4.0 | .10 | 3.40 |
| Ireland | 1.50 | 2.20 | 1.3 | .10 | 1.80 |
| Norway | 5.00 | 4.00 | 3.0 | .25 | 3.00 |
| Sweden | 4.50 | 2.90 | 3.1 | .10 | 2.90 |
| Switzerland | 3.40 | 2.90 | 1.1 | .10 | 2.90 |
| United Kingdom | 4.60 | 2.20 | 2.1 | .20 | 2.70 |
| Other Western Europe: | 4.40 | 2.10 | 4.3 | .30 | 3.10 |
| Greece | 4.00 | 3.50 | 2.0 | .10 | 3.00 |
| Portugal | 3.20 | 1.90 | 1.6 | .20 | 1.30 |
| Spain | 4.00 | 3.50 | 3.7 | .30 | 3.50 |
| Turkey | -- | 1.50 | 6.2 | .40 | 1.50 |
| Yugoslavia | 5.50 | 4.50 | 5.0 | .30 | 5.00 |
| Oceania: | 2.70 | 2.40 | .3 | .02 | 2.40 |
| Australia | 3.00 | 2.20 | .4 | .10 | 2.50 |
| New Zealand | 2.00 | 2.70 | .1 | .10 | 2.50 |
| OECD-Oceania | 5.40 | 3.50 | 2.9 | .16 | 3.40 |

-- = Not applicable.

Source: (804).

Table 44--Developed countries: Grain utilization rates for livestock production, 1985

(Kilograms of grain fed per kilogram of product)

| Region or country | Pork | Poultry | Beef and veal | Milk | Eggs |
|---|---|---|---|---|---|
| | | | Rate | | |
| United States | 8.30 | 4.20 | 4.0 | 0.30 | 4.00 |
| Canada | 7.80 | 2.10 | 4.0 | .30 | 3.70 |
| Japan | 6.30 | 2.40 | 1.7 | .10 | 2.40 |
| OECD-Europe | 3.30 | 2.70 | 2.5 | .13 | 2.90 |
| | | | | | |
| European Community: | 2.90 | 2.90 | 2.1 | .08 | 3.00 |
| Belguim-Luxembourg | 2.68 | 2.52 | 2.0 | .07 | 2.12 |
| Netherlands | 2.63 | 2.52 | 2.5 | .10 | 2.51 |
| France | 2.85 | 2.52 | 2.6 | .09 | 2.50 |
| Germany | 2.43 | 2.87 | 1.4 | .07 | 2.59 |
| Italy | 5.50 | 3.20 | 1.6 | .10 | 4.20 |
| | | | | | |
| North Western Europe: | 3.80 | 2.20 | 2.5 | .16 | 2.70 |
| Austria | 3.60 | 2.50 | 1.6 | .10 | 3.20 |
| Denmark | 4.40 | 2.20 | 2.4 | .10 | 3.10 |
| Finland | 5.00 | 2.80 | 4.0 | .10 | 3.80 |
| Ireland | 1.30 | 1.90 | 1.3 | .10 | 1.60 |
| Norway | 4.50 | 4.00 | 2.7 | .20 | 2.70 |
| Sweden | 4.00 | 2.40 | 3.1 | .10 | 2.60 |
| Switzerland | 3.50 | 2.40 | 1.4 | .10 | 2.50 |
| United Kingdom | 4.00 | 1.90 | 2.5 | .20 | 2.50 |
| | | | | | |
| Other Western Europe: | 4.00 | 2.70 | 4.5 | .32 | 2.90 |
| Greece | 3.50 | 3.00 | 2.5 | .10 | 3.00 |
| Portugal | 3.30 | 2.00 | 1.7 | .20 | 1.60 |
| Spain | 3.50 | 3.00 | 4.2 | .40 | 3.00 |
| Turkey | -- | 2.00 | 6.5 | .40 | 2.00 |
| Yugoslavia | 5.00 | 4.00 | 5.0 | .30 | 4.50 |
| | | | | | |
| Oceania: | 3.00 | 2.40 | .3 | .02 | 2.20 |
| Australia | 3.40 | 2.20 | .4 | .10 | 2.30 |
| New Zealand | 2.50 | 2.60 | .1 | .10 | 2.30 |
| | | | | | |
| OCED-Oceania | 5.00 | 3.30 | 3.1 | .16 | 3.30 |

-- = Not applicable.

Source: (804).

as to the intensity of grain feeding and oilmeal feeding in given regions in producing specified meats and dairy products incorporated into the World GOL Model. These judgments are tentative and subject to revision. The Organization for Economic Cooperation and Development (OECD) has questioned member countries about feeding practices. Tabulation of OECD member country response has served as a basis for scaling input-output coefficients relative to feed demand among OECD members which are represented in the GOL model. Data for 1962, 1975, and 1985 feed grain utilization rates (tables 42, 43, and 44) are in basic harmony with the Main Sequence and have served as an important point of departure for modeling the developed countries, including Oceania (and by implication and inference, Argentina).

The United States, Canada, Japan, and parts of Western Europe possess grain-intensive beef cattle industries; in Europe, this industry is on the increase. Elsewhere, the grain-intensive meat industries are pork and poultry production. In many parts of the world, beef production is appropriately considered to be a byproduct of the dairy industry. Great difficulties exist, and arbitrary judgment cannot be avoided, in allocating feed to poultry meat as compared to eggs, and to beef as compared to milk. In many parts of the world, the allocation must be made among beef, milk, and work, for oxen continue to be important for power and beef (in some regions, even cows in lactation are used for work).

Three literary traditions have been consulted in developing the physical input-output relationships bearing on Europe and North America. Best known to agricultural economists in the United States and other English-speaking countries is Morrison, Feeds and Feeding (1046). This work was in the 22nd edition in 1956. It is closely consulted concerning problems involving animal feeding. A similar compendium of feeding data is in constant revision in the German language. Kellner, Grundzerege der Futterungslehre (1040) is in its 14th edition. It is available in English translation dating back to 1926 as Scientific Feeding of Animals (1039). This work undertakes, for the northern European environment, a role similar to Morrison for North America. As Morrison's work is identified with Cornell University, Kellner's is identified with Goettingen University in the Federal Republic of Germany, where it has made the agricultural research station at Weende famous.

An offshoot of the Weende approach continues work at Rostock University in the German Democratic Republic. Kurt Nehring and his followers have carried out extensive original studies. Their contribution to science is suggested by citations here in the name of Nehring, such as his Lehrbuch der Tierernaehrung und Futtermittelkunde (1047) (freely translated to Principles of Animal Nutrition and Feeding), and the key articles in a comprehensive series (1048, 1049, 1050, and 1051).

The literature cited here is useful to determine variations in geographic distribution of feeding practice, the variability of nutrient plants, and the effect of harvesting practices, weather, and handling on nutrient quality of feeds.

## Price-Elasticity Matrix

Price adjustment terms based on estimates of direct- and cross-price elasticities for livestock products and for feed inputs are introduced into the same derived demand equations containing the input-output coeffients. Research has shown that derived feed demand equations perform well when estimated on the basis of price series that are ratios of product prices to feed input prices. Such relationships cannot be utilized in the present model, because the price terms in the ratios are nonlinear functions of the numerators and denominators of the ratios. The World GOL Model requires linearity among the endogenous variables. For elasticities estimated in ratios of prices, therefore, elasticities of equal absolute value were assigned to numerator and denominator; however, the sign was changed for the denominator. In these expressions, positive elasticities on meat prices, for instance, imply that an increase in a meat price brings an increase in feed use. Negative price elasticities on feeds, correspondingly, imply that a rise in a feed price brings a drop in feeding.

ESCS researchers have developed regression equations of the type discussed above for the United States (table 45) and the European Community (table 46). They serve as the basis for assigning the numerical values to the price elasticities incorporated into the equations of derived demand for feed grain and oilmeal. The analysis of feed demand for the United States is by Ahalt and Egbert (102); the analysis for the EC-6 is by Regier (see appendix C).

## Longrun Feeding Growth

Longrun exogenous impacts, in general, are not great as far as livestock feeding is concerned, since most of the relevant variables are GOL endogenous. They are shown in conjunction with livestock supply growth terms in table 36.

Affluence is expected to continue to rise throughout the world. In general, this factor is expected to operate through growth in demand for meat and a consequent rise in livestock prices. Nevertheless, it can also have a direct impact on the interface between crop and livestock products. Since, in a given region, not all meats or dairy products may be included, the expected average effect on that part of the livestock economy not explicitly modeled is treated by growth terms or income elasticities acting with augmented impact upon the derived feed equations. Anticipated developments affecting the livestock sector not explicitly modeled are handled in this fashion. Expected growth in the force of input-output rates also is built into the longrun growth factors. Discerned trends in styles of livestock feeding are of this nature. Increased use of wheat in livestock feeding is a similar force.

For those components of derived demand not directly related to meat production by way of input-output coefficients, much higher income elasticities are used for feed grain than those used for direct human demand for grain. The derived demand income elasticities more nearly resemble those associated with direct demand for meat than for grain used as food. A calculation is given in appendix D showing the derivation of such income elasticities from the livestock sector and showing the theoretical nature of price elasticities where income-output factors are not directly connected in the model to livestock production.

## World GOL Model Feed Demand Parameters

The factors discussed throughout this section have been quantified for each GOL region containing a livestock sector and are presented in tables 47 and 48 for grain and oilmeal, respectively. The tables show, by region, input-output rates, price elasticities, and, where needed, income elasticities and market shares.

In each region, the feed grain demand function is seen to be related to 10 or more interrelated factors. The oilmeal demand function is similarly structured. Nearly all the endogenous variables of the GOL model impinge on these equations.

# PROJECTION PERFORMANCE

The elasticities of meat supply and demand and the parameters of derived demand for livestock feed presented in this volume have been used, along with similar sets of grain supply elasticities and elasticities for aspects of grain demand other than livestock feed, for developing projections to 1985. The projections cover regional

Table 45--United States: Demand for livestock feed 1/

| Feed use | Price ratio PLF | Production | | Constant K | $R^2$ |
|---|---|---|---|---|---|
| | | LPU | GAU | | |
| Total concentrates: | | | | | |
| FC | 0.233 | 0.878 | -- | -68.053 | 0.96 |
| | (.075) | (.115) | | | |
| | E .250 | E 1.280 | | | |
| FC | .519 | -- | 0.806 | -79.466 | .81 |
| | (.157) | | (.599) | | |
| | E .580 | | E 1.04 | | |
| Feed grain: | | | | | |
| FG | .215 | .720 | -- | -64.470 | .96 |
| | (.067) | (.103) | | | |
| | E .250 | E 1.280 | | | |
| High protein feed: | | | | | |
| FH | -- | .165 | -- | -16.493 | .95 |
| | | (.010) | | | |
| | | E 2.150 | | | |

-- = Not applicable.

1/ FC is total feed concentrates fed, in million tons (121.9 in 1955);
FG is total feed grains fed, in million tons (95.9 in 1955);
FH is total high-protein concentrates fed, in million tons (14.1 in 1955);
PLF is the ratio of the price of livestock and livestock products to the price of feed grain and hay, index 1910-14=100 (128 in 1955);
LPU is total livestock production units, in millions (187.7 in 1955);
GAU is total grain-consuming animal units, in millions (165.3 in 1955);
K is the linear regression constant;
$R^2$ is the coefficient of multiple determination;
E is an elasticity;
Standard errors are reported in parentheses.

Source: (102).

Table 46--EC-6: Demand for livestock feed 1/

| Feed use | Price ratio: PMG | Price ratio: PMO | Price ratio: POG | Price ratio: PGO | Production XM | Constant K | $R^2$ DW |
|---|---|---|---|---|---|---|---|
| Feed grain: | | | | | | | |
| FG | 0.491 | -- | -- | -- | 1.123 | -62.945 | 0.97 |
| | (.266) | | | | (.095) | | 1.27 |
| | E .510 | | | | E 1.260 | | |
| FG | .521 | -- | -0.128 | -- | .881 | -31.671 | .99 |
| | (.129) | | (.054) | | (.108) | | 2.13 |
| | E .550 | | E -.140 | | E .910 | | |
| Oilmeal feed: | | | | | | | |
| FO | -- | 1.144 | -- | -1.430 | 3.134 | -183.377 | .98 |
| | | (.530) | | (.506) | (.417) | | 2.23 |
| | | E .970 | | E-1.150 | E 2.770 | | |

-- = Not applicable.

1/ FG is feed consumption of grain, index of physical tonnage, 1960 = 100;
FO is feed consumption of oilmeal, index of physical tonnage, 1960 = 100;
PMG is the ratio of the price of meat to the price of grain, 1960 = 100;
PMO is the ratio of the price of meat to the price of oilmeal, 1960 = 100;
POG is the ratio of the price of oilmeal to the price of grain, 1960 = 100;
XM is domestic production of meat and livestock, index of physical tonnage, 1960 = 100;
K is the linear regression constant;
$R^2$ is the coefficient of multiple determination;
DW is the Durbin-Watson statistic;
E is an elasticity;
Standard errors are reported in parentheses.

Source: Appendix C.

Table 47--World GOL Model: Factors affecting use of grain as livestock feed

| Factors | United States | Canada | EC-6 | EC-3 | Other Western Europe | Japan |
|---|---|---|---|---|---|---|
| | Kilogram grain use per kilogram product | | | | | |
| Input-output rate: | | | | | | |
| Beef, finished | 5.74 | -- | -- | -- | -- | -- |
| Beef, other | 2.02 | 4.60 | 1.300 | 2.27 | 2.46 | 2.33 |
| Pork | 6.43 | 6.50 | 3.600 | 4.22 | 4.60 | 5.09 |
| Poultry | 2.76 | 2.90 | 2.700 | 2.70 | 2.80 | 2.40 |
| Lamb and mutton | 1.86 | -- | .250 | .25 | -- | -- |
| Milk | .33 | .33 | .125 | .21 | .28 | .20 |
| Eggs | 2.91 | 3.10 | 3.100 | 3.10 | -- | 2.40 |
| | Percentage change in grain use per unit percentage change in price | | | | | |
| Price elasticity: | | | | | | |
| Beef, finished | .22 | -- | -- | -- | -- | -- |
| Beef, other | .03 | .25 | -- | -- | -- | -- |
| Pork | .25 | .25 | .50 | .50 | .40 | .50 |
| Corn | -.40 | -.40 | -.50 | -.50 | -.50 | -.60 |
| Oilseed cake | .10 | .10 | .10 | .10 | .10 | .10 |

| Factors | Australia and New Zealand | South Africa | Eastern Europe | U.S.S.R. | People's Republic of China | Mexico and Central America |
|---|---|---|---|---|---|---|
| | Kilogram grain use per kilogram product | | | | | |
| Input-output rate: | | | | | | |
| Beef, other | 0.30 | -- | 2.80 | 3.00 | -- | 0.30 |
| Pork | 3.40 | -- | 4.60 | 5.00 | 2.0 | 3.00 |
| Poultry | 3.00 | -- | 3.00 | 3.50 | 1.0 | -- |
| Milk | .12 | -- | .30 | .30 | -- | -- |
| Eggs | 3.00 | -- | 3.10 | 3.50 | -- | -- |
| | Percentage change in grain use per unit percentage change in price | | | | | |
| Price elasticity: | | | | | | |
| Beef, other | -- | -- | -- | -- | -- | .20 |
| Pork | .30 | -- | .25 | -- | -- | -.20 |
| Corn | -.30 | -.30 | -.25 | -- | -- | -- |
| | Percentage change in grain use per unit percentage change in income | | | | | |
| Per capita income elasticity | -- | .25 | -- | -- | -- | .10 |

Continued--

Table 47--World GOL Model: Factors affecting use of grain as livestock feed--Continued

| Factors | Argentina | Brazil | Venezuela | Other South America | North Africa-Middle East: High | North Africa-Middle East: Low |
|---|---|---|---|---|---|---|
| | Kilogram grain use per kilogram product | | | | | |
| Input-output rates: | | | | | | |
| Beef, other | 0.50 | 1.50 | -- | -- | -- | -- |
| Pork | 3.60 | 3.60 | -- | -- | -- | -- |
| | Percentage change in grain use per unit percentage change in price | | | | | |
| Price elasticity: | | | | | | |
| Pork | .30 | .30 | -- | -- | -- | -- |
| Corn | -.30 | -.40 | -.30 | -.40 | -.30 | -.15 |
| Oilseed cake | -- | .10 | -- | -- | -- | -- |
| | Percentage change in grain use per unit percentage change in income | | | | | |
| Per capita income elasticity | .20 | .20 | .20 | .20 | .30 | .10 |

| Factors | East Africa | Central Africa | India | Other South Asia | Thailand | Other Southeast Asia |
|---|---|---|---|---|---|---|
| | Kilogram grain use per kilogram product | | | | | |
| Input-output rate: | | | | | | |
| Milk | -- | -- | .05 | -- | -- | -- |
| | Percentage change in grain use per unit percentage change in income | | | | | |
| Price elasticity: | | | | | | |
| Corn | -.30 | -- | -.40 | -.20 | -.1 | -.3 |
| | Percentage change in grain use per unit percentage change in income | | | | | |
| Per capita income elasticity | .20 | .15 | .40 | .20 | .1 | .2 |
| | Grain use as a proportion of commodity supply | | | | | |
| Market shares (commodity supply feed grain) | -- | -- | .15 | -- | -- | -- |

Continued--

Table 47--World GOL Model: Factors affecting use of grain as livestock feed--Continued

| Factors | Indonesia | East Asia | | Other areas |
|---|---|---|---|---|
| | | High | Low | |
| | Percentage change in grain use per unit percentage change in price | | | |
| Price elasticity: | | | | |
| Corn | -.30 | -.50 | -.30 | -- |
| | Percentage change in grain use per unit percentage change in income | | | |
| Per capita income elasticity | .30 | .40 | .20 | -- |

-- = Not applicable.

Sources:
Input-Output Rates--generalization to other regions of the balancing method used in (145)-for the EC-6, see tables 39, 40, and 41 for feed-livestock balances of the EC-6 and the United States and for derivation of feed input-output rates. Compare feed input-output rates in (804, 201, and 113); data on livestock feed requirements in (501-505) for the United States and (506-510) for European countries; and treatises on livestock feeding (1046, 1039-1040, and 1074). See discussion of the Main Sequence in "Structure of the World GOL Model," especially table 2 and appendix B, and (148).
Price Elasticities--synthesized in the light of "Structure of the World GOL Model" for conformity with empirical price elasticities in (102) and in appendices B and C.

Table 48--World GOL Model: Factors affecting use of oilmeal as livestock feed

| Factors | United States | Canada | EC-6 | EC-3 | Other Western Europe | Japan |
|---|---|---|---|---|---|---|
| | Kilogram oilmeal use per kilogram product | | | | | |
| Input-output rate: | | | | | | |
| Beef, finished | 0.25 | -- | -- | -- | -- | -- |
| Beef, other | .44 | 0.10 | 0.16 | 0.12 | 0.15 | 0.50 |
| Pork | .45 | .35 | .67 | .55 | .65 | 1.40 |
| Poultry | .87 | .60 | 1.18 | 1.05 | 1.16 | 1.20 |
| Lamb and mutton | 1.72 | -- | -- | -- | -- | -- |
| Milk | .033 | .03 | .033 | .025 | .028 | .08 |
| Eggs | .47 | .35 | .71 | .60 | -- | .70 |
| | Percentage change in oilmeal use per unit percentage change in price | | | | | |
| Price elasticity: | | | | | | |
| Beef, finished | -.10 | -- | -- | -- | -- | -- |
| Beef, other | .23 | -- | -- | -- | -- | -- |
| Pork | .27 | .90 | 1.20 | 1.80 | 1.00 | 1.20 |
| Corn | 1.00 | 2.50 | .90 | 1.00 | 1.20 | 1.50 |
| Oilseed cake | -.53 | -.98 | -.25 | -.37 | -.20 | -.30 |

| Factors | Australia and New Zealand | South Africa | Eastern Europe | U.S.S.R. | People's Republic of China | Mexico and Central America |
|---|---|---|---|---|---|---|
| | Kilogram oilmeal use per kilogram product | | | | | |
| Input-output rate: | | | | | | |
| Pork | -- | -- | 0.40 | 0.40 | 0.40 | -- |
| Poultry | -- | -- | .50 | .50 | .50 | -- |
| Milk | -- | -- | .01 | .01 | -- | -- |
| Eggs | -- | -- | .13 | .40 | -- | -- |
| | Percentage change in oilmeal use per unit percentage change in price | | | | | |
| Price elasticity: | | | | | | |
| Pork | -- | -- | -- | -- | -- | 0.20 |
| Corn | -- | -- | -- | -- | -- | -.20 |
| Oilseed cake | -0.30 | -- | -- | -- | -- | -- |
| | Oilmeal use as a proportion of commodity demand | | | | | |
| Market share (commodity demand feed grain) | -- | 0.19 | -- | -- | -- | 0.32 |

| Factors | Argentina | Brazil | Venezuela | Other South America | North Africa-Middle East: High | North Africa-Middle East: Low |
|---|---|---|---|---|---|---|
| | Percentage change in oilmeal use per unit percentage change in price | | | | | |
| Price elasticity: | | | | | | |
| Oilseed cake | -0.50 | -0.40 | -- | -0.30 | -- | -- |

Continued--

Table 48--World GOL Model: Factors affecting use of oilmeal as livestock feed--Continued

| Factors | Argentina | Brazil | Venezuela | Other South America | North Africa-Middle East | |
|---|---|---|---|---|---|---|
| | | | | | High | Low |
| | Oilmeal use as a proportion of commodity supply | | | | | |
| Market shares (commodity demand feed grain) | .047 | .064 | -- | .21 | .30 | -- |

| Factors | East Africa | Central Africa | India | Other South Asia | Thailand | Other Southeast Asia |
|---|---|---|---|---|---|---|
| | Kilogram oilmeal use per kilogram product | | | | | |
| Input-output rate: Milk | -- | -- | .10 | -- | -- | -- |
| | Percentage change in oilmeal use per unit percentage change in price | | | | | |
| Price elasticity: Oilseed cake | -- | -- | -.20 | -- | -- | -- |
| | Percentage change in oilmeal use per unit percentage change in income | | | | | |
| Per capita income elasticity | -- | -- | .10 | -- | -- | -- |

| Factors | Indonesia | East Asia | | Other Areas |
|---|---|---|---|---|
| | | High | Low | |
| | Percentage change in oilmeal use per unit percentage change in price | | | |
| Price elasticity: Oilseed cake | -.20 | -.30 | -- | -- |
| | Percentage change in oilmeal use per unit percentage change in income | | | |
| Per capita income elasticity | .30 | .30 | -- | -- |

-- = Not applicable.

Source: See table 47 and sources cited.

balances of production, consumption, trade, and prices for the commodity categories making up the grain, oilseed, and livestock complex in a world context. The basic inputs to the World GOL Model are population, income and technology growth rates, the elasticities and parameters referred to in this publication, similar elasticities for the grain and oilseed sectors, 1970 price and quantity data, and assumptions about underlying economic conditions, institutions, and policies. These projections are presented in companion volumes prepared in the Commodities Program Area, Foreign Demand and Competition Division, ESCS: Anthony S. Rojko, et al; Alternative Futures for World Food in 1985. Under this comprehensive heading are the separate publications: Volume 1, World GOL Model Analytical Report (157) and Volume 2, World GOL Model Supply-Distribution and Related Tables (158), which present the projections, describe the scenarios, and interpret the results, and Volume 3, World GOL Model Structure and Equations (159), which presents the full economic model. Full details are presented in these volumes of the implications of the projection alternatives developed and the computational backgrounds. The focus of attention in this study is on the interaction between meat production and the projected use of grain and oilmeal as feed.

Summary totals of world and commodity aggregates from alternative projections to 1985 developed with the GOL model are presented in tables 49 to 53. Aspects of the 1970 base and six alternative 1985 projections are shown for the world total and the subtotals for developed countries (DC) and less developed countries (LD). The world total is the sum of these two regional categories, ignoring the central plan countries (CP) whose structural features have not yet been incorporated into the GOL model. The tables are designed to facilitate comparison of aspects of world grain and oilmeal consumption and meat and livestock production. Total grain consumption has been partitioned into food grain, used as human food, and feed grain, used as livestock feed. Calculated with the World GOL Model are the feed grain and oilmeal categories as directly related to the meat production columns.

It is apparent from table 49 that the variation from low to high in the alternative projections affects all commodities shown in similar fashion, all tending to flex upward or downward together. The stability of DC food grain consumption in all the alternative projections is the exception to the generality of the foregoing proposition. The absolute variation in DC food grain consumption and LD feed grain consumption is slight among alternative projections. The strong downward flexing in both DC feed grain consumption and meat production in alternative III is also notable. These conclusions are strengthened by reference to table 50. This result suggests, if the GOL model is realistically designed, that the livestock sector acts as a large, inconspicuous grain reserve helping to stabilize food grain consumption. The high volume elements in the grain demand pattern, in terms of absolute tonnage, are LD food grain and DC feed grain. This is where the volume grain markets are and appear likely to remain.

Tables 50, 51, and 52 show the change expected to occur in these commodity categories under the stipulated alternative projection conditions. Table 50, showing market growth in terms of 1970 levels, confirms the relatively small change expected for DC food grain demand and the much higher growth in DC feed use based on strong growth in DC livestock production. The higher growth in LD food grain is evident. However, the high dynamic element in LD feed grain consumption is clearly revealed. Some alternative projections generate a doubling in LD feed use over the 15-year period and an expansion by two-thirds in the most parsimonious of the alternatives for 1985. The DC market for feed grain is large and growing, while the LD market for feed grain, though modest in scale, is growing faster.

The compound annual growth rates shown in table 51 largely confirm the observations facilitated by table 50. It is now evident that food grain consumption in the DC's is expanding at less than constant per capita annual rates (0.8 percent),

Table 49--World GOL Model: World grain and oilmeal consumption and meat production, 1970 base and alternative 1985 projection levels 1/

| Base and alternative projection | Grain consumption | | | | | | | | | Oilmeal consumption | | | Meat production 2/ | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Total | | | Food | | | Feed | | | | | | | | |
| | World | DC | LD | World | DC | LD | World | DC | LD | World | DC | LD | World | DC | LD |
| | Million tons | | | | | | | | | | | | | | |
| 1970 base | 674 | 374 | 299 | 391 | 121 | 270 | 282 | 253 | 29 | 42 | 36 | 6 | 70 | 50 | 20 |
| 1985: | | | | | | | | | | | | | | | |
| I | 971 | 493 | 478 | 561 | 134 | 427 | 410 | 359 | 51 | 71 | 60 | 11 | (100) | 66 | (34) |
| I-A | 947 | 481 | 465 | 548 | 132 | 416 | 398 | 349 | 49 | 73 | 62 | 11 | ( 99) | 66 | (33) |
| II | 1034 | 522 | 512 | 586 | 132 | 454 | 448 | 390 | 58 | 75 | 64 | 11 | (103) | 68 | (35) |
| III | 918 | 453 | 465 | 551 | 134 | 417 | 367 | 319 | 48 | 66 | 55 | 11 | ( 96) | 63 | (32) |
| IV | 1048 | 528 | 520 | 596 | 135 | 461 | 452 | 393 | 59 | 73 | 62 | 11 | (105) | 70 | (35) |
| IV-B | 1056 | 529 | 526 | 601 | 135 | 466 | 454 | 394 | 60 | 73 | 62 | 11 | (105) | 70 | (35) |

1/ Total grain is the sum of food grain and feed grain. World totals are sum of subtotals for developed countries (DC) and less developed countries (LD), omitting central plan countries (CP). Detail sums to total except for rounding.

2/ LD meat production projections are partly estimated outside the model, as indicated by parentheses. All other projections are developed by the World GOL Model.

Table 50--World GOL Model: Growth in world grain and oilmeal consumption and meat production, projected 1985 levels expressed as percentages of 1970 base levels 1/

| Base and alternative projection | Grain consumption | | | | | | | | | Oilmeal consumption | | | Meat production | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Total | | | Food | | | Feed | | | | | | | | |
| | World | DC | LD | World | DC | LD | World | DC | LD | World | DC | LD | World | DC | LD |
| | Percent of 1970 2/ | | | | | | | | | | | | | | |
| 1970 base | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| 1985: | | | | | | | | | | | | | | | |
| I | 144 | 132 | 160 | 143 | 111 | 158 | 145 | 142 | 176 | 169 | 167 | 183 | 143 | 132 | 170 |
| I-A | 141 | 129 | 156 | 140 | 109 | 154 | 141 | 138 | 169 | 174 | 172 | 183 | 141 | 132 | 165 |
| II | 153 | 140 | 171 | 150 | 109 | 168 | 159 | 154 | 200 | 179 | 178 | 183 | 147 | 136 | 175 |
| III | 136 | 121 | 156 | 141 | 111 | 154 | 130 | 126 | 166 | 157 | 153 | 183 | 137 | 126 | 160 |
| IV | 155 | 141 | 174 | 152 | 112 | 171 | 160 | 155 | 203 | 174 | 172 | 183 | 150 | 140 | 175 |
| IV-B | 157 | 141 | 176 | 154 | 112 | 173 | 161 | 156 | 207 | 174 | 172 | 183 | 150 | 140 | 175 |

1/ Total grain is the sum of food grain and feed grain. World totals are sum of subtotals for developed countries (DC) and less developed countries (LD), omitting central plan countries (CP). Detail sums to total except for rounding.
2/ Percentages are calculated from table 49.

Table 51--World GOL Model: Growth rates of world grain and oilmeal consumption and meat production, compound growth rates over the period 1970 to 1985 alternative levels 1/

| Base and alternative projection | Grain consumption | | | | | | | | | Oilmeal consumption | | | Meat production | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Total | | | Food | | | Feed | | | | | | | | |
| | World | DC | LD | World | DC | LD | World | DC | LD | World | DC | LD | World | DC | LD |
| | Percent per annum 2/ | | | | | | | | | | | | | | |
| 1985: | | | | | | | | | | | | | | | |
| I | 2.5 | 1.9 | 3.2 | 2.4 | .7 | 3.1 | 2.5 | 2.4 | 3.8 | 3.6 | 3.5 | 4.1 | 2.4 | 1.9 | 3.6 |
| I-A | 2.3 | 1.7 | 3.0 | 2.3 | .6 | 2.9 | 2.3 | 2.2 | 3.6 | 3.8 | 3.7 | 4.1 | 2.3 | 1.9 | 3.4 |
| II | 2.9 | 2.3 | 3.7 | 2.7 | .6 | 3.7 | 3.1 | 2.9 | 5.7 | 3.9 | 3.9 | 4.1 | 2.6 | 2.1 | 3.8 |
| III | 2.1 | 1.3 | 3.0 | 2.3 | .7 | 2.9 | 1.8 | 1.6 | 3.4 | 3.1 | 2.9 | 4.1 | 2.1 | 1.6 | 3.2 |
| IV | 3.0 | 2.3 | 3.8 | 2.9 | .7 | 3.6 | 3.2 | 3.0 | 4.9 | 3.8 | 3.7 | 4.1 | 2.7 | 2.3 | 3.8 |
| IV-B | 3.0 | 2.3 | 3.8 | 2.9 | .7 | 3.7 | 3.2 | 3.0 | 5.0 | 3.8 | 3.7 | 4.1 | 2.7 | 2.3 | 3.8 |

1/ Total grain is the sum of food grain and feed grain. World totals are sum of subtotals for developed countries (DC) and less developed countries (LD), omitting central plan countries (CP). Detail sums to total except for rounding.

2/ Percentages and growth rates are calculated from table 49.

Table 52--World GOL Model: Variability among alternative projections to 1985 of world grain and oilmeal consumption and meat production 1/

| Commodity | Extreme variation among projections | | | | | |
|---|---|---|---|---|---|---|
| | Absolute difference | | | Proportion low to high | | |
| | World | DC | LD | World | DC | LD |
| | ----- Million tons ----- | | | ----- Percent ----- | | |
| Consumption: | | | | | | |
| Total grain | 138 | 76 | 61 | 87 | 86 | 88 |
| Food grain | 53 | 3 | 50 | 91 | 98 | 89 |
| Feed grain | 87 | 75 | 12 | 81 | 81 | 80 |
| Oilmeal | 9 | 9 | 0 | 90 | 89 | 100 |
| Meat production | 9 | 7 | 3 | 91 | 90 | 91 |

1/ In this table the requirement that detail sums to total is relaxed. Conceptually, food grain plus feed grain still sum to total grain, and developed countries (DC) plus less developed countries (LD) sum to the world, omitting central plan countries (CP). These equations hold within given projection alternatives. However, this table is a comparison of the GOL model's sensitivity from one alternative to another. In preparing the table, it did not develop and it was not expected that the greatest DC variation in feed grain would involve the same alternatives as DC variation in food grain, or LD variation in either feed grain or food grain. Calculations are based on data in table 49.

whereas other grain demand categories tend to expand much more rapidly. LD feed demand, for example, is seen as expanding at upwards of 5 percent annually in some alternatives, while gaining on LD per capita growth (2.7 percent) in all others.

Oilmeal demand exhibits much the same pattern of growth as feed grain, but with appreciably greater growth rates in general.

Tables 49 to 51 suggest that feed consumption largely tracks developments occurring in meat production. Table 52 reveals that feed grain demand is more volatile than meat production, swinging through wider proportional variation. Oilmeal use, however, tends to track meat production more closely. The feed conversion rates expressing the quantity of feed used to obtain a given quantity of meat are quite stable among the alternative projections (table 53). In general, feed utilization rates tend to be more intense than in the base 1970 period; however, in some comparisons, the differences are slight. (See figure 7 for grain/meat and oilmeal meat conversion.) Quite simply, low grain conversion rates in combination with low volume output of meat generates the low swing in feed grain demand. Low meat prices relative to grain, in the GOL model, tend to inhibit both meat production and grain feeding. Similarly, high prices of grain relative to oilmeal tend to discourage grain feeding in favor of oilmeal feeding.

The alternative III projection deserves comment in this context. The DC and LD use rates are at the base 1970 levels in this alternative, while the aggregate use rate for the world (less CP) is 5 percent below the base 1970 level. The implication here is that the simultaneous calculations with the World GOL Model have revealed a significantly greater sensitivity to price circumstances in DC than in LD meat pro-

## World: Grain/meat and oilmeal/meat feed conversion

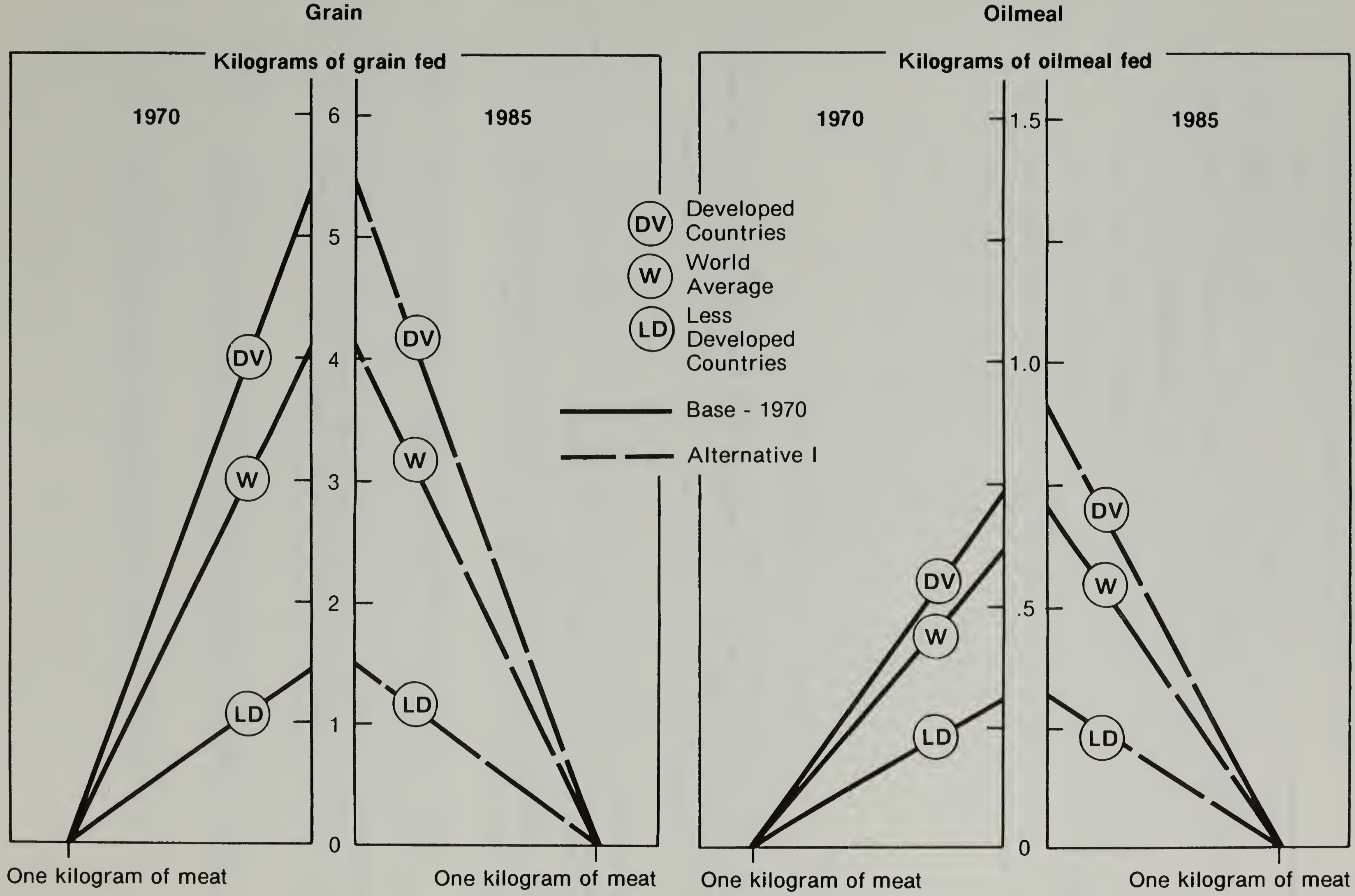



Figure 7

Table 53--World GOL model: World feed utilization rates, 1970 and 1985 projected alternatives 1/

| Base and projections | Grain use rate | | | Oilmeal use rate | | |
|---|---|---|---|---|---|---|
| | World | DC | LD | World | DC | LD |
| | Kilograms 2/ | | | | | |
| 1970 base | 4.03 | 5.06 | 1.45 | 0.60 | 0.72 | 0.30 |
| 1985: | | | | | | |
| I | 4.10 | 5.44 | 1.50 | .71 | .91 | .32 |
| I-A | 4.02 | 5.39 | 1.48 | .74 | .94 | .33 |
| II | 4.35 | 5.74 | 1.66 | .73 | .97 | .31 |
| III | 3.82 | 5.06 | 1.50 | .69 | .87 | .34 |
| IV | 4.30 | 5.61 | 1.69 | .70 | .89 | .31 |
| IV-B | 4.32 | 5.63 | 1.71 | .70 | .89 | .31 |

1/ World use rates are averages of developed countries (DC) and less developed countries (LD) use rates omitting central plan countries(CP). Calculations are based on data in table 49.
2/ Kilograms of grain or oilmeal used to produce a kilogram of meat.

duction. The practical effect of this result is to reveal DC meat production as a regulator of the world grain supply--a second level reserve for severe contingencies. This result will become a working hypothesis as the World GOL Model is put into advanced modeling phases. The result may be partly attributable to the use of collapsed (reduced form) feed demand equations for the LD livestock economies in some regions.

Possibly the most important implication of the behavior of the livestock sector in projection performance (after the relative stability of the feed utilization rates) is the relative variability of the quantity estimates of feed demand resulting from simultaneous effects of calculations with the model. Where meat production and food grain demand fluctuate in a 10-percent range from high to low (the same as oilmeal), feed grain use fluctuates in a 20-percent range. Feed grain demand is the most dynamic demand element in the World GOL Model.

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Fitted regression equations, performed originally or taken from the literature of agricultural economics, typically have the form --

$$X_i = f( X_o ) + g( Z ) \qquad \text{.(A-1)}$$

-- where $X_i$ is one of the variables endogenous to GOL, $X_o$ stands for any set of the other GOL-endogenous variables, and Z is any GOL-exogenous factors. Collecting terms gives--

$$X_i - f( X_o ) = g( Z ). \qquad \text{.(A-2)}$$

Arranging these expressions into a set of matrices with the functions of the $X_o$ formed into a matrix F, as defined in the main text, and matching the $X_i$ with I, the identity matrix having ones in the principal diagonal and zeros elsewhere, leads to--

$$(I - F)\ X = G( Z ) \qquad \text{.(A-3)}$$

--and this, if we write A for (I - F) and H for G( Z ), is --

$$AX = H \qquad \text{.(A-4)}$$

--the basic equation of the World GOL Model.

While the A-matrix is required to be linear, the H-matrix with the exogenous variables is not so restricted. The form of H depends on assumptions as to impacts expected of particular exogenous variables included in GOL. The general form of H is --

$$H = B\ (1 + R)^T + CZ + DT + E \qquad \text{.(A-5)}$$

--where the impacts may take some combination of the following forms:

$$H_1 = B\ ( \ + R)^T + E_1 \qquad \text{.(A-5.1)}$$

$$H_2 = CZ + E_2 \qquad \text{.(A-5.2)}$$

$$H_3 = DT + E_3 \qquad \text{.(A-5.3)}$$

$H_1$, $H_2$, and $H_3$ sum to H in the general form and $E_1$, and $E_2$, and $E_3$ to E. The first form ($H_1$) is a compound growth process where B is a vector of bases to be compounded, R is a set of growth rates for particular exogenous processes, and T is the number of years over which compounding occurs. The second form ($H_2$) represents a linear relationship to some exogenous variables where C is the coefficient matrix and Z a vector of exogenous variables. The third form ($H_3$) is simply an allowance for linear trends where D is the matrix of trend increments and T is the span of years over which the trends operate.

For any projection alternative, the H-matrix is collapsed into a 930-term S-vector of the solution set of H. All terms of H are individually projected before S can be calculated and the variations in the endogenous variables (X) determined. Solving H for the appropriate alternative S and premultiplying by the inverse of A --

$$X = A^{-1}S \qquad \text{.(A-6)}$$

--yields the variation in X which constitutes the GOL projection alternative reflecting the particular assumptions about H which are inherent in S.

The World GOL Model is based, in part, on projections in Agricultural Trade and the Proposed Round of Multilateral Negotiations, the so-called "Flanigan Report" prepared by USDA in 1970 and released by the U.S. Senate Committee on Agriculture and Forestry (165). The GOL model is partly a computerization of these projections. The World GOL Model was first used for projections published in World Food Situation and Prospects to 1985 (114), which was followed by Rojko, "Estimating Future Demand: Alternative Grain Projections for 1985" (153). Broad characteristics of the GOL model itself were discussed by Rojko and Schwartz in an article titled "Modeling the World Grain-Oilseeds-Livestock Economy to Assess World Food Prospects" (160). Two articles by Rojko and O'Brien, using GOL-generated projections, appeared under the heading "Organizing Agriculture in the Year 2000" (155 and 156).

After further development and adjustment, the projection output of the World GOL Model was presented in companion volumes under the general heading Alternative Futures for World Food in 1985. In this series, Volume 1, World GOL Model Analytical Report (157) by Rojko, Regier, O'Brien, Coffing, and Bailey, and Volume 2, World GOL Model Supply-Distribution and Related Tables (158) by Rojko, O'Brien, Regier, Coffing, and Bailey give full details of various projection alternatives, the complex of assumptions underlying each, the implications of the assumptions, and the results. Volume 3, World GOL Model Structure and Equations (159) by Rojko, Fuchs, O'Brien, and Regier sets out the complete economic model in mathematical form.

As to documentation of the grain sector, counterpart of the livestock documentation found here, the GOL model is a second generation product. Much of the documentation of the earlier World Grain Model applies to the grain sector of the World GOL Model. The central study on the earlier model is Rojko, Urban, and Naive, World Demand Prospects for Grain in 1980 (161). Other studies in the same series are the following: Rojko and Mackie, World Demand Prospects for Agricultural Exports of Less Developed Countries in 1980 (154); Hutchison, Naive, and Tsu, World Demand Prospects for Wheat in 1980 (130); Keefer, Barry, Pike, and Gill, World Demand Prospects for Rice in 1980 (133); Moe and Mohtadi, World Supply and Demand Prospects for Oilseeds and Oilseed products in 1980 (142); and Regier and Goolsby, Growth in World Demand for Feed Grains 1980 (148).

A forerunner of the World Grain Model is a small 1967 bulletin by Abel and Rojko entitled The World Food Situation (101), a subject on which Willett has prepared a two-volume compendium of papers (168).

The World GOL Model builds on three main streams of development in quantitative economics. The first is the Engel (1017) and Le Play (1048) tradition mentioned in the main text in connection with the Main Sequence.

Second is the determination of individual demand and supply functions building directly on methods of a number of commodity analysts. In this field, Henry Schultz' Theory and Measurement of Demand (1063) is a landmark. A number of USDA technical bulletins are standards of quality and application of methods in the feed-livestock sectors: Breimyer (106), Foote, Klein and Clough (120), Fox (121), Gerra (123), Harlow (126), Hodges (222), Jennings (223), King (134), Meinken (139, 140), and Rojko (151).

The third is the analysis of the structure of economic systems, entirely or in part, which owes much to Walras (1071) working in the late 19th century. With the advent of the computer, theory and application went hand in hand. Hicks (1031) and Samuelson (1061), to name just two, delineated pure theory in mathematical form. Heady (1028 and 1029) led in applying the new theory to production. Frisch (1022), followed by Brandow (1012), George and King (1024), and Alm, Duloy, and Gullbrandsen (1001), paced the application to consumption and demand. This work has led to simultaneous estimation of systems of commodity equations and their structural parameters, which the GOL model draws on heavily. At the same time, it has produced computer methods for solving large equation systems, such as the World GOL Model, and extrapolating or projecting the results.

## APPENDIX B--Main Sequence of Meat, Grain, and Feed

### Documentation of Data for the World

Definitions:

POP is population in units of 10 million, calculated from FAO data (604, vol. 2, table I.1).

YPC is per capita income, specifically--for worldwide comparability--gross domestic product in 1962 dollar equivalent, calculated from FAO data (604, vol. 2, table I.3).

PMG is the price ratio of meat price to grain price, calculated from FAO data (604, vol. 2, table I.14).

MPC is meat consumption per capita in kilograms per annum (including beef, veal, pork, poultry, mutton, lamb, goat, game, and other), calculated from FOA data (604, vol. 2, table A).

GPC is grain consumption per capita for food in kilograms per annum (including wheat, corn, rice, coarse grain, sorghums, millets, and other), calculated from FAO data (604, vol. 2, table A).

RGM is the grain-meat ratio, an input-output ratio expressing the quantity (e.g., kilograms) of grain actually used in producing one unit (e.g., kilogram) of meat, calculated from ERS data (148, appendix table 1).

BOV is the percentage which meat from bovine animals (mainly beef, veal, and buffalo) is to total meat produced, calculated from ERS data (148, appendix table 5, citing 112 and 203 through 207).

PTY is the percentage which poultry meat is to total meat produced, calculated from ERS data (148, appendix table 5, citing 112 and 203 through 207).

XMB is the joint-product ratio of milk production as a multiple of beef production, calculated from ERS data (148, appendix table 5, citing 112 and 203 through 207).

### Equations

Meat Consumption per Capita

$$MPC = -\underset{(.0085)}{.0226}\, PMG + \underset{(.0018)}{.0317}\, YPC - \underset{(.0170)}{.1145}\, INY + 33.6709 \quad \ldots\ldots\ldots \quad (1)$$

$R^2 = .835$

Grain Consumption per Capita for Food

$$lgGPC = - \underset{(.0525)}{.4305}\ lgPGM - \underset{(.0624)}{.4436}\ lgYPC - \underset{(.0258)}{.2579}\ INY + 4.3350 \qquad (2)$$

$R^2 = .560$

Grain-Meat Ratio

$$RGM = \underset{(.0001)}{.0001}\ YPC - \underset{(.0021)}{.0271}\ INY - \underset{(.0050)}{.0120}\ BOV + \underset{(.0165)}{.0690}\ PTY$$

$$+ \underset{(.0027)}{.0117}\ XMB + \underset{(.2831)}{.9201}\ DEV + \underset{(.2016)}{.7523}\ PLN + 3.367 \qquad (3)$$

$R^2 = .722$

Feed Grain Consumption per Capita

$$FPC + RGM\ (\ MPC\ ) \qquad (4)$$

Grain Consumption per Capita for Food and Feed

$$TPF = GPC + FPC \qquad (5)$$

Income Determination from Consumption

$$YPC = \underset{(10.0511)}{66.9030}\ PMG + \underset{(1.0515)}{20.7467}\ MPC + \underset{(9.4003)}{105.8089}\ GCD - \underset{(194.6016)}{2333.3427}\ (GCD)^{\frac{1}{2}}$$

$$- \underset{(.0125)}{.1307}\ (MCD)(GCD) - \underset{(.0133)}{.1550}\ (MCL)\ (GCL) + \underset{(985.8299)}{13353.7103}\ DEV$$

$$+ \underset{(30.8493)}{285.5607}\ LDC - 597.8641 \qquad (6)$$

$R^2 = .964$

Variables in the Equations

The variables are defined as:

MPC is per capita consumption of meat in kilograms per annum.

GPC is per capita consumption of grain for food in kilograms per annum.

RGM is the grain-meat ratio, understood as the number of kilograms of grain actually accounted for in producing one kilogram of meat.

FPC is per capita consumption of grain as livestock feed in kilograms per annum.

TPC is per capita consumption of grain for food and feed.

YPC is per capita gross domestic product in U.S. dollar equivalent.

INY is the inverse of YPC, as above, multiplied by 10,000.

PMG is the price ratio of a kilogram of meat to a kilogram of grain.

PGM is the price ratio of a kilogram of grain to a kilogram of meat.

BOV is meat from bovine animals as a percentage of total meat production.

PTY is poultry meat as a percentage of total meat production.

XMB is the milk-beef ratio, understood as the joint product ratio of milk to beef.

MCD is per capita consumption of meat in a developed country.

MCL is per capita consumption of meat in a less developed country.

GCD is per capita consumption of grain in a developed country.

GCL is per capita consumption of grain in a less developed country.

DEV is a variable which is 1 for a developed country; otherwise 0.

LDC is a variable which is 1 for a less developed country; otherwise 0.

PLN is a variable which is 1 for a central plan country; otherwise 0.

lg indicates a variable in logarithms to the base 10.

( ) numbers in parentheses are standard errors.

The data are in world cross section by country for 1962, or centered on that year, or as close to it as possible, as developed by ESCS, FAS, and FAO. The data are presented in appendix table 1. (Communist Asia in the table refers to all those Asian countries with a communist political system in 1970.)

## APPENDIX C--EC-6 Feed-Livestock Sector Equations

The equations reproduced here are from a 1971-working paper by Regier titled "The EEC Feed-Livestock Economy: An Analytical Model" (170) revised in May 1977. This document contains the data series assembled and aggregated by the author for the original six members of the European Community and cites the sources of the data used.

### Variables

#### Endogenous Variables

CM is human consumption of meat, in millions of metric tons, carcass weight.

CG is human consumption of grain, in million tons.

FG is feed consumption of grain, in million tons.

FO is feed consumption of oilmeal, in million tons.

NG is industrial (and other) consumption of grain, in million tons.

IG is net imports of grain, in million tons.

IO is net imports of oilmeal equivalent, in million tons.

dHG is increase in stocks of grain, in million tons.

IM is net imports of meat, in million tons, carcass weight equivalent.

IL is net imports of livestock, in million tons, carcass weight equivalent.

XM is domestic production of meat and livestock, in million tons, carcass weight.

XG is domestic production of grain, in million tons.

XO is domestic production of oilmeal equivalent, in million tons.

DM is total demand for meat, in million tons.

DG is total demand for grain, in million tons.

DO is total demand for oilmeal, in million tons.

SM is total supply of meat, in million tons.

SG is total supply of grain, in million tons.

PM is price received by farmers for meat, index 1960 = 100.

PG is price received by farmers for grain, index 1960 = 100.

PO is price received by farmers for oilmeal, index 1960 = 100.

MPC is human consumption of meat per capita, in kilograms.

GPC is human consumption of grain per capita, in kilograms.

Endogenous Variables--continued

PMG is ratio of price of meat to price of grain, index 1960 = 100.

PMO is ratio of price of meat to price of oilmeal, index 1960 = 100.

POG is ratio of price of oilmeal to price of grain, index 1960 = 100.

PGO is ratio of price of grain to price of oilmeal, index 1960 = 100.

Predetermined Endogenous Variables

$XM_{-1}$ is domestic production of meat a year ago.

$XG_{-1}$ is domestic production of grain a year ago.

$XO_{-1}$ is domestic production of oilmeal equivalent a year ago.

$SM_{-1}$ is total supply of meat a year ago.

$SG_{-1}$ is total supply of grain a year ago.

$SO_{-1}$ is total supply of oilmeal equivalent a year ago.

$PM_{-1}$ is price of meat a year ago.

$PG_{-1}$ is price of grain a year ago.

$PO_{-1}$ is price of oilmeal a year ago.

Exogenous Variables

CE is private consumption expenditure, index 1960 = 100.

EPC is private consumption expenditure per capita, index 1960 = 100.

YG is grain yield, output per unit of input, in tons per hectare.

DT is a variable which equals -3 in 1951, -2 in 1952, -1 in 1953, and 0 thereafter.

T is time, employed generally as a proxy for technology growth.

K is regression constant, or other autonomous constant.

Auxiliary Variables and Symbols

FGM is kilograms of grain fed to livestock per kilogram of meat produced.

FOM is kilograms of oilmeal fed to livestock per kilogram of meat produced.

FGO is ratio of quantity of grain fed to quantity of oilmeal fed to livestock, index 1960 = 100.

lg is logarithm to the base 10.

Auxiliary Variables and Symbols--continued

mt is million metric tons; all quantities are in metric measure.

I is index number, generally base 1960 = 100.

R is rate: e.g., kilograms of input used per kilogram of product.

E is elasticity, shown beneath regression coefficients.

$R^2$ is coefficient of determination, squared multiple correlation coefficient.

SE is standard error of the estimate.

DW is Durbin-Watson statistic.

OLS is ordinary least squares regression estimation is used. Standard errors are shown in parentheses below corresponding regression coefficients. Below these are shown values of each variable, both dependent and independent, at the data means. Below these are shown elasticities calculated at the data means, where such elasticities are deemed appropriate.

## Equations

(1) Human Demand for Meat

| | | | | | |
|---|---|---|---|---|---|
| CM | = - .01256 PM + | .00888 PG + | .03962 CE + | .17401 T - 4.39996 | |
| | (.00637) | (.00836) | (.01005) | (.04894) | |
| mt 9.38 | 101.7 | 100.4 | 98.5 | 59.0 | $R^2$ .998 |
| | E -.14 | E .09 | E .42 | | SE .94% |
| | | | | | DW 1.55 |

(2) Human Demand for Grain

| | | | | |
|---|---|---|---|---|
| CG | = - .05000 PG - | .02978 CE - | .00728 T + 31.1107 | |
| | ( c ) | (.02439) | (.14141) | |
| mt 22.50 | 93.1 | 117.5 | 62.5 | $R^2$ .921 |
| | E -.21 | E -.16 | | SE 1.06% |
| | | | | DW 2.23 |

(3) Feed Demand for Grain

| | | | | |
|---|---|---|---|---|
| FG | = .52106 PMG - | .12844 POG + | .88128 XM - 31.67096 | |
| | (.12885) | (.05378) | (.10477) | |
| I 98.95 | 105.01 | 109.06 | 102.02 | $R^2$ .986 |
| | E .55 | E -.14 | E .91 | SE 2.49% |
| | | | | DW 2.13 |

(4) Feed Demand for Oilmeal

| | | | | |
|---|---|---|---|---|
| FO | = 1.14390 PMO - | 1.43036 PGO + | 3.13366 XM - 183.37674 | |
| | (.52991) | (.50626) | (.41655) | |
| I 115.5 | 97.91 | 92.89 | 102.12 | $R^2$ .976 |
| | E .97 | E -1.15 | E 2.77 | SE 6.87% |
| | | | | DW 2.23 |

(5) Industrial (and other) Demand for Grain

| | | | |
|---|---|---|---|
| NG | = - .00816 PG + | .01935 CE + 4.89543 | |
| | (.03115) | (.00945) | |
| mt 7.15 | 93.21 | 155.56 | $R^2$ .925 |
| | E -.11 | E .42 | SE 2.88% |
| | | | DW 2.23 |

(6) Domestic Production of Meat

| | | | | |
|---|---|---|---|---|
| XM | = .01940 PM - | .00488 PG + | .32602 T - 11.59439 | |
| | ( c ) | ( c ) | (.00975) | |
| mt 9.46 | 101.41 | 98.67 | 59.45 | $R^2$ .984 |
| | E .21 | E .05 | | SE 2.72% |
| | | | | DW 1.44 |

(7) Supply of Meat

| | | |
|---|---|---|
| SM | = 1.16564 XM - 1.06764 | |
| | (.01840) | |
| mt 9.96 | 9.46 | $R^2$ .996 |
| | E 1.11 | SE 1.48% |
| | | DW 1.08 |

(8) Supply of Grain

$$SG = .13300\ PG + .46207\ YG + 1.38915\ T - 46.29658$$

| | PG | YG | T | |
|---|---|---|---|---|
| | ( c ) | (.16924) | | |
| mt 9.96 | 93.09 | 26.16 | | $R^2$ .992 |
| | E .19 | E .19 | | SE 1.13% |
| | | | | DW 2.67 |

(9) Supply of Oilmeal

$$SO = .03169\ PO + .59214\ T - 34.49389$$

| | PO | T | |
|---|---|---|---|
| | (.01830) | (.05565) | |
| mt 5.59 | 99.99 | 62.0 | $R^2$ .982 |
| | E .58 | | SE 6.09% |
| | | | DW 1.91 |

(10) Domestic Production of Meat

$$XM = .01940\ PM_{-1} - .00488\ PG_{-1} + .32791\ T - 11.71559$$

| | $PM_{-1}$ | $PG_{-1}$ | T | |
|---|---|---|---|---|
| | ( c ) | ( c ) | (.01026) | |
| mt 9.46 | 101.48 | 99.85 | 60.0 | $R^2$ .984 |
| | E .21 | E -.05 | | SE 2.59% |
| | | | | DW .98 |

(11) Supply of Grain

$$SG = .16655\ PG_{-1} + .30978\ YG + 1.53459\ T - 55.25894$$

| | $PG_{-1}$ | YG | T | |
|---|---|---|---|---|
| | ( c ) | (.14515) | (.12375) | |
| mt 65.00 | 97.56 | 26.13 | 62.5 | $R^2$ .994 |
| | E .25 | E .125 | | SE 1.02% |
| | | | | DW 2.26 |

(12) Supply of Oilmeal

$$SO = .02953\ PO_{-1} + .60086\ T - 34.90759$$

| | $PO_{-1}$ | T | |
|---|---|---|---|
| | (.01925) | (.06194) | |
| mt 5.59 | 101.48 | 62.43 | $R^2$ .980 |
| | E .54 | | SE 6.00% |
| | | | DW 1.88 |

(13) Net Imports of Grain

$$IG = -\ .15080\ PG - .93293\ XG + 3.00765\ XM + .88586\ dHG + 44.45244$$

| | PG | XG | XM | dHG | |
|---|---|---|---|---|---|
| | (.11522) | (.15042) | (.44763) | (.19083) | |
| mt 9.74 | 93.09 | 55.77 | 10.27 | .513 | $R^2$ .893 |
| | E -1.44 | E -5.34 | E 3.17 | E .047 | SE 1.33% |
| | | | | | DW 2.24 |

(14) Net Imports of Oilmeal

$$IO = .02808\ PO + .57064\ T - 33.01526$$

| | PO | T | |
|---|---|---|---|
| | (.01762) | (.05357) | |
| mt 5.17 | 99.99 | 62.0 | $R^2$ .983 |
| | E .54 | | SE 6.11% |
| | | | DW 2.00 |

(15) Increase in Grain Stocks

| | | | | | |
|---|---|---|---|---|---|
| dHG | = | .38938 PG + | .60856 XG − 69.67200 | | |
| | | (.11158) | (.14780) | | |
| mt | .51 | 93.09 | 55.77 | | $R^2$ .630 |
| | | E 70.7 | E 66.2 | | SE 2.10%: XG |
| | | | | | DW 2.47 |

(16) Net Imports of Livestock, Meat Equivalent

| | | | | | |
|---|---|---|---|---|---|
| IL | = | .00682 PM + | .04688 XM − .88089 | | |
| | | (.00190) | (.00341) | | |
| mt | .25 | 101.41 | 9.29 | | $R^2$ .918 |
| | | E 2.77 | E 1.74 | | SE .31%: XM |
| | | | | | DW 1.42 |

(17) Net Imports of Meat

| | | | | | |
|---|---|---|---|---|---|
| IM | = | .01892 PM − | .01765 PG + | .02097 SM − .14637 | |
| | | (.00576) | (.00611) | (.03095) | |
| mt | .25 | 101.41 | 98.67 | 9.78 | $R^2$ .905 |
| | | E 8.12 | E −7.37 | E .8 | SE .89% |
| | | | | | DW 1.37 |

(18) Domestic Production of Grain

| | | | | | |
|---|---|---|---|---|---|
| XG | = | .06765 PG + | 2.14131 YG − 6.54292 | | |
| | | (.09842) | (.25865) | | |
| mt | 56.36 | 93.09 | 26.16 | | $R^2$ .823 |
| | | E .11 | E .99 | | SE 1.59% |
| | | | | | DW 2.46 |

(19) Domestic Production of Oilmeal (Equivalent)

| | | | | | |
|---|---|---|---|---|---|
| XO | = | .00361 PO + | .02151 T − 1.47933 | | |
| | | (.00148) | (.00451) | | |
| mt | .215 | 99.99 | 62.0 | | $R^2$ .823 |
| | | E 1.68 | | | SE 12.37% |
| | | | | | DW 1.30 |

(20) Net Imports of Livestock, Meat Equivalent

| | | | | | |
|---|---|---|---|---|---|
| IL | = | .00266 $PM_{-1}$ − | .00120 $PG_{-1}$ + | .03982 $XM_{-1}$ − .26231 | |
| | | (.00221) | (.00207) | (.01181) | |
| mt | .25 | 101.48 | 99.85 | 9.17 | $R^2$ .889 |
| | | E 1.06 | E −.47 | E 1.44 | SE .33%: SM |
| | | | | | DW 1.61 |

(21) Net Imports of Meat

| | | | | | |
|---|---|---|---|---|---|
| IM | = | .01819 $PM_{-1}$ − | .00958 $PG_{-1}$ + | .07093 $SM_{-1}$ − 1.32376 | |
| | | (.00587) | (.00659) | (.03224) | |
| mt | .25 | 101.48 | 99.85 | 9.58 | $R^2$ .905 |
| | | E 7.50 | E −3.89 | E 2.76 | SE .89%: SM |
| | | | | | DW 1.78 |

(22) Domestic Production of Meat

$$XM = .01960\ PM_{-1} - .00488\ PG_{-1} + .32791T - 11.71559$$

| | | | | | |
|---|---|---|---|---|---|
| | ( c ) | ( c ) | (.01026) | | |
| mt 9.46 | 101.48 | 99.85 | 60.0 | $R^2$ | .984 |
| | E .21 | E -.05 | | SE | 2.59% |
| | | | | DW | .98 |

(23) Domestic Production of Grain

$$XG = .11946\ PG_{-1} + 2.23055\ YG - 13.91846$$

| | | | | |
|---|---|---|---|---|
| | (.09192) | (.21698) | | |
| mt 56.36 | 94.39 | 26.45 | $R^2$ | .987 |
| | E .20 | E 1.05 | SE | 1.56% |
| | | | DW | 2.24 |

(24) Domestic Production of Oilmeal

$$XO = .00127\ PO_{-1} + .01649\ T - .94176$$

| | | | | |
|---|---|---|---|---|
| | (.00064) | (.00314) | | |
| mt .215 | 105.72 | 62.0 | $R^2$ | .801 |
| | E .62 | | SE | 13.12% |
| | | | DW | 1.19 |

## Additional Equations

### Human Demand for Meat per Capita

(A-1)

$$MPC = -\ .18772\ PM + .71114\ EPC + .73633\ DT + 47.30033$$

| | | | | | |
|---|---|---|---|---|---|
| | (.06389) | (.01384) | (.33219) | | |
| I 97.67 | 101.81 | 98.07 | | $R^2$ | .998 |
| | E -.20 | E .71 | | SE | .85% |
| | | | | DW | 1.98 |

(A-2)

$$MPC = -\ .19634\ PM + .13553\ PG + .77671\ EPC + .82321\ DT + 28.17222$$

| | | | | | | |
|---|---|---|---|---|---|---|
| | (.05795) | (.06868) | (.03551) | (.30364) | | |
| I 97.67 | 101.81 | 100.38 | 98.07 | | $R^2$ | .998 |
| | E -.21 | E .14 | E .78 | | SE | .76% |
| | | | | | DW | 2.78 |

### Human Demand for Grain per Capita

(A-3)

$$GPC = -\ .20000\ PG - .16353\ EPC - 1.03719\ T + 199.40098$$

| | | | | | |
|---|---|---|---|---|---|
| | ( c ) | (.23778) | (1.06220) | | |
| I 97.38 | 93.21 | 113.47 | 62.5 | $R^2$ | .947 |
| | E -.19 | E -.19 | | SE | 1.94% |
| | | | | DW | 2.40 |

### Feed Demand for Grain

(A-4)

$$FG = .52106\ PMG - .12844\ POG + .88128\ XM - 31.67096$$

| | | | | | |
|---|---|---|---|---|---|
| | (.12885) | (.05378) | (.10477) | | |
| I 97.95 | 105.01 | 109.06 | 102.02 | $R^2$ | .986 |
| | E .55 | E -.14 | E .91 | SE | 2.49% |
| | | | | DW | 2.13 |

(A-5) FG = − .81631 PG − .19596 PO + .56833 XM + 141.48572

| | | | | | |
|---|---|---|---|---|---|
| | | (.13494) | (.03710) | (.10289) | |
| | I 97.95 | 97.44 | 107.03 | 102.02 | $R^2$ .994 |
| | | E −.80 | E −.21 | E .59 | SE 1.67% |
| | | | | | DW 2.52 |

(A-6) lgFG = .00150 lgPM − .62760 lgPG − .07904 lgPO + .70679 lgXM
(.26397) (.18773) (.21556) (.24832)

+ .01775 DT + 1.98286
(.01012)

$R^2$ .994
SE .42%
DW 2.07

(A-7) lgFG = .39352 lgPMG + .94324 lgXM + .01802 DT − .68980
(.10559) (.07753) (.00350)

$R^2$ .992
SE .86%
DW 2.23

Feed Demand for Oilmeal

(A-8) FO = 1.14390 PMO − 1.43036 PGO + 3.13366 XM − 183.37674

| | | | | | |
|---|---|---|---|---|---|
| | | (.52991) | (.50626) | (.41655) | |
| | I 115.46 | 97.91 | 92.89 | 102.12 | $R^2$ .976 |
| | | E .97 | E −1.15 | E 2.77 | SE 6.87% |
| | | | | | DW 2.23 |

(A-9) FO = − 1.59136 PG + .12067 PO + 2.88901 XM − 37.13181

| | | | | | |
|---|---|---|---|---|---|
| | | (.82886) | (.22788) | (.63203) | |
| | I 115.46 | 97.44 | 107.03 | 102.02 | $R^2$ .970 |
| | | E −1.34 | E .11 | E 2.55 | SE 8.80% |
| | | | | | DW 2.07 |

(A-10) lgFO = .75960 lgPM −1.03629 lgPG − .33067 lgPO
(.90273) (.60644) (.29081)

+ 2.37796 lgXM − 1.54348
(.63176)

$R^2$ .986
SE 1.45%
DW 2.54

(A-11) lgFO = .40784 lgPMO + 2.92348 lgXM − .00407 DT − 4.65212
(.53880) (.37770) (.03314)

$R^2$ .976
SE 3.50%
DW 1.86

(A-12) lgFO = −1.29914 lgPG − .47427 lgPO + 2.03670 lgXM + 1.47767
(.51216) (.23201) (.47728)

$R^2$ .984
SE 2.90%
DW 2.62

Feeding Rates and Substitution

| | | | | | |
|---|---|---|---|---|---|
| (A-13) FGM | = .01490 PMG + | .00248 XM + 1.56910 | | | |
| | (.00619) | (.00434) | | | |
| R 3.386 | 104.014 | 102.021 | | $R^2$ | .707 |
| | E .46 | E .075 | | SE | 3.60% |
| | | | | DW | .92 |

| | | | | | |
|---|---|---|---|---|---|
| (A-14) FGM | = .01294 PMG + | .00219 XM + | .13327 DT + 2.30878 | | |
| | (.00349) | (.00261) | (.02670) | | |
| R 3.386 | 104.01 | 102.02 | | $R^2$ | .916 |
| | E .40 | E -.07 | | SE | 2.02% |
| | | | | DW | 2.27 |

| | | | | | |
|---|---|---|---|---|---|
| (A-15) FOM | = .00500 PMO + | .00760 XM - | .04572 DT - .80995 | | |
| | (.00301) | (.00202) | (.03277) | | |
| R .475 | 97.91 | 102.02 | | $R^2$ | .949 |
| | E 1.03 | E 1.63 | | SE | 8.17% |
| | | | | DW | 1.92 |

| | | | | | |
|---|---|---|---|---|---|
| (A-16) FGO | = - .31938 PGO - | 1.70295 XM + 299.68417 | | | |
| | (.24126) | (.18101) | | | |
| I 96.28 | 92.89 | 102.02 | | $R^2$ | .939 |
| | E -.31 | E -1.80 | | SE | 7.39% |
| | | | | DW | 2.02 |

| | | | | | |
|---|---|---|---|---|---|
| (A-17) FGO | = - .44486 PGO - | .59199 PMO - | 1.30069 XM + 332.46755 | | |
| | (.23550) | (.35181) | (.29196) | | |
| I 96.28 | 92.89 | 105.01 | 102.02 | $R^2$ | .953 |
| | E -.43 | E -.65 | E -1.38 | SE | 6.84% |
| | | | | DW | 2.32 |

## APPENDIX D--Feed Demand in a Collapsed Livestock Sector

The approach employed in the GOL model for reflecting the influence of livestock quantities and prices in certain regions without explicitly including these variables is from Rojko, Urban, and Naive (178). The quantification of certain key assumptions about the livestock sector enables calculation of a modified demand equation for feed grain in replacement of families of demand and supply equations for individual livestock commodities and equations reflecting their equivalent in feed.

We begin with a simple livestock model:

Demand for livestock products

(1) $Q_L^d + 2P_L = 2Y$

Supply of livestock products

(2) $Q_L^s - 3P_L = -2P_G + 3T$

Equilibrium condition

(3) $Q_L = Q_L^s = Q_L^d$

Where:

$Q_L^d$ = Quantity of livestock products demanded

$Q_L^s$ = Quantity of livestock products supplied

$P_L$ = Price of livestock products

$Y$ = Income

$P_G$ = Price of coarse grains

$T$ = Trend variable

$Q_L$ = Equilibrium quantity for livestock products

The prices and quantities of livestock products are assumed to be endogenous, while the remaining variables are exogenous. Also, there are no imports of livestock products; this restriction will be lifted later.

In matrix form, equations (1) to (3) may be reduced to:

$$\begin{bmatrix} 1 & 2 \\ 1 & -3 \end{bmatrix} \begin{bmatrix} Q_L \\ P_L \end{bmatrix} = \begin{bmatrix} 2 & 0 & 0 \\ 0 & -2 & 3 \end{bmatrix} \begin{bmatrix} Y \\ P_G \\ T \end{bmatrix}$$

(4)
$$\begin{bmatrix} Q_L \\ P_L \end{bmatrix} = \begin{bmatrix} 1.2 & -.8 & 1.2 \\ .4 & .4 & -.6 \end{bmatrix} \begin{bmatrix} Y \\ P_G \\ T \end{bmatrix}$$

From equation set (4), we can write:

(4a)
$$Q_L = 1.2Y - .8P_G + 1.2T$$

If we are given the technical relation

(5)
$$Q_G = 4Q_L$$

where $Q_G$ refers to quantity of grain, we can substitute (5) in (4a) and recombine to obtain the following derived demand for grains in terms of feed grain prices.

Derived demand for grains

(6)
$$.25Q_G^d + .8P_G = 1.2Y + 1.2T$$

Supply of grains

(7)
$$Q_G^d - 2P_G = 1.5T$$

Equation (6) is in the desired form for use as a demand equation along with the supply equation (7) in the world grain model.

Now, even though the world grain model uses only grain prices, it implicity takes into account the joint interactions due to $P_L$ and $Q_L$ in equations (1) and (2) by use of equation set (4). Specifically, for every $Q_G^d$ generated by the world grain model, there is a corresponding $Q_L$ and $P_L$ which can be estimated by use of equation (4).

So far, it has been assumed that there would be imports of grain but no imports of livestock products. One way of introducing imports of livestock products would be to assume a deliberate policy of maintaining some degree of self-sufficiency. For example, 80 percent self-sufficiency could be introduced by modifying equation (3) to

(3a) $$Q_L = Q_L^s = 0.8Q_L^d$$

If parameters had been used instead of constants for coefficients, then:

(I) $$Q_L^d + aP_L = bY$$

(II) $$Q_L^s + cP_L = dP_G + eT$$

(III) $$Q_L = Q_L^s = Q_L^d$$

In matrix form:

$$\begin{bmatrix} 1 & a \\ 1 & c \end{bmatrix} \begin{bmatrix} Q_L \\ P_L \end{bmatrix} = \begin{bmatrix} b & o & o \\ o & d & e \end{bmatrix} \begin{bmatrix} Y \\ P_G \\ T \end{bmatrix}$$

$$\begin{bmatrix} Q_L \\ P_L \end{bmatrix} = \begin{bmatrix} 1 & a \\ 1 & c \end{bmatrix}^{-1} \begin{bmatrix} b & o & o \\ o & d & e \end{bmatrix} \begin{bmatrix} Y \\ P_G \\ T \end{bmatrix}$$

$$\begin{bmatrix} Q_L \\ P_L \end{bmatrix} = \frac{1}{c - a} \begin{bmatrix} c & -1 \\ -a & 1 \end{bmatrix} \begin{bmatrix} b & o & o \\ o & d & e \end{bmatrix} \begin{bmatrix} Y \\ P_G \\ T \end{bmatrix}$$

(IV) $$\begin{bmatrix} Q_L \\ P_L \end{bmatrix} = \frac{1}{c - a} \begin{bmatrix} cb & cd & ce \\ -ab & -ad & -ae \end{bmatrix} \begin{bmatrix} Y \\ P_G \\ T \end{bmatrix}$$

(IVa) $$Q_L = \frac{cb}{c - a} Y + \frac{cd}{c - a} P_G + \frac{ce}{c - a} T$$

Which is equivalent to equation (4a).

Letting equation (5) be:

(V) $$Q_G = kQ_L$$

We obtain by substituting (V) into (IVa) and recombining:

$$Q_G = \frac{kcd}{c - a} P_G + \frac{kcb}{c - a} Y + \frac{kce}{c - a} T$$

Which is equivalent to equation (6).

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